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AERONAUTICS

NINETEENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1933

ADMINISTRATIVE REPORT
WITHOUT TECHNICAL REPORTS

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON: 1934

LETTER OF SUBMITTAL

To the Congress of the United States:

Pursuant to the act of March 3, 1915, which established the National Advisory Committee for Aeronautics, I submit herewith the Nineteenth Annual Report of that Committee for the fiscal year ended June 30, 1933.

The attention of the Congress is invited to the opening pages of the Committee's report giving the major reasons for the recent improvements in the speed and efficiency of airplanes for military and civil uses. The principal underlying cause of this remarkable progress has been the efficient functioning of the National Advisory Committee for Aeronautics in coordinating and planning for the research needs of aviation, civil and military, and in conducting the necessary fundamental scientific researches to serve the needs of all agencies.

I concur in the Committee's opinion that the continuous prosecution of fundamental research in aeronautics is essential to the national defense and to the future of air transportation upon a sound economic basis.

Franklin D. Roosevelt.

The White House,
January 12, 1934.

LETTER OF TRANSMITTAL

National Advisory Committee for Aeronautics,
Washington, D.C., December 15, 1933.

Mr. President:

In compliance with the provisions of the act of Congress approved March 3, 1915 (U.S.C., title 50, sec. 153), I have the honor to transmit herewith the Nineteenth Annual Report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1933.

The past year has to an unprecedented degree witnessed the application by the Army, the Navy, and the aircraft industry of the cumulative results of years of fundamental research conducted by this Committee to meet the needs of military and civil aviation. It saw greater improvement in the speed of aircraft and in economy of operation than has been made in any single year since the war.

Higher speeds have introduced new problems into a heavily crowded program of investigations. The Committee is energetically prosecuting a comprehensive research program to serve all needs, and is confident that continued support of its work will continue to yield results of immeasurable military value and of economic value greatly in excess of its annual appropriations. The independent status of the Committee has been the most vital factor in its success and is essential to its continued efficient functioning.

Respectfully submitted.

Joseph S. Ames, *Chairman.*

The President,
The White House, Washington, D.C.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, NAVY BUILDING, WASHINGTON, D.C.

LABORATORIES, LANGLEY FIELD, VA.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight. Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
MATERIALS FOR AIRCRAFT
PROBLEMS OF AIR NAVIGATION
AIRCRAFT ACCIDENTS
INVENTIONS AND DESIGNS

Coordination of Research Needs of Military and Civil Aviation

Preparation of Research Programs

Allocation of Problems

Prevention of Duplication

Consideration of Inventions

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

LANGLEY FIELD, VA.

Unified conduct for all agencies of scientific research on the fundamental problems of flight.

OFFICE OF AERONAUTICAL INTELLIGENCE

WASHINGTON, D.C.

Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics.

NINETEENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D.C., *November 14, 1933.*

To the Congress of the United States:

In accordance with the act of Congress approved March 3, 1915, which established the National Advisory Committee for Aeronautics, the Committee submits herewith its nineteenth annual report for the fiscal year 1933.

Continued progress.—It is gratifying to the Committee to report that the past year was notable as witnessing the greatest advance in airplane performance and efficiency accomplished in any single year since the Great War. This is largely the cumulative result of years of organized scientific research conducted by this Committee and of the practical application of the results by the Army, the Navy, and the aircraft industry.

Result of sound governmental policy.—In the opinion of the Committee aeronautical development in the United States is certainly abreast, and, in certain particulars, in advance of the development in any other country. This is the result of long-continued sound governmental policy in supporting fundamental aeronautical research. It began with legislation 18 years ago which established the National Advisory Committee for Aeronautics as an independent Government establishment "to supervise and direct the scientific study of the problems of flight," and has been continued through generous appropriations to this Committee. Thus one central governmental organization, with the active cooperation of the War, Navy, and Commerce Departments and of the aircraft industry, supplies the research needs of aviation. By this policy of coordination, results of greatest value to aeronautics are obtained with prevention of duplication and waste. Supplementing this policy, there is effective application of the results of the Committee's researches in the experimental and development laboratories of the Army and Navy.

Comprehensive researches serve all needs.—The research programs of the Committee are formulated largely by the various technical subcommittees whose membership embraces all governmental agencies concerned. A large part of the Committee's research programs consists of specific requests of the Army and Navy air organizations. The latter depend upon the Committee for the scientific study and investigation of fundamental problems necessary for the improved design of military and naval aircraft. Aircraft manufacturers and operators also rely upon the Committee for fundamental data, and the Committee broadens its military and naval researches to obtain as much fundamental information as possible in order to meet the needs of civil and commercial aviation. In this the Committee is assisted by the cooperation of the Aeronautics Branch of the Department of Commerce and by an annual conference with represetatives of the aircraft industry, held at the research laboratories at Langley Field, Va.

Facilities for fundamental research.—The Committee has recognized its responsibility in shaping the progress of aeronautics and, with the far-sighted support of the Comgress, has anticipated the research needs of aviation and developed at Langley Field, Va., the best-equipped aeronautical research laboratory in the world. This one central laboratory is known as the Langley Memorial Aeronautical Laboratory and is operated under the single and direct control of the Committee. The fundamental researches approved by the Committee are conducted at that laboratory, where there are combined under ideal conditions facilities for laboratory investigations and for researches on airplanes in flight. Much of the equipment there is original and ingenious and permits investigations that give results not obtainable in any other country. The development of this laboratory represents in itself an accomplishment in which the Congress and the country may take pride, for the excellence of its product has gained for the United States an advantageous position among the progressive nations in the development of aeronautics.

Results of research.—Speed is still the most important single factor in increasing the relative importance of aircraft for national defense and in extending their use for commercial purposes. Primarily as a direct result of the Committee's researches there have been great increases in speed and efficiency during the past year, which have opened a new era in the development of both military and commercial aircraft. The increase in the speed of multiengine airplanes, military and commercial, from 1932 to 1933 has approximated 40 to 60 percent with practically the same engine power. This development is one of the outstanding contributions of the Committee, the major factors being:

(1) The National Advisory Committee for Aeronautics engine location and cowling. (The results of the cowling research were published in 1928. The results of the engine location research were issued confidentially to the Army, Navy, and industry in 1930, and were kept confidential until 1932, when the first American airplanes embodying the principles had been designed and actually constructed.)

(2) The development by the Army, the Navy, and the industry of reliable retractable landing gears.

(3) Increased horsepower with same size and weight of engines, involving increased revolutions per minute, higher compression ratio, improved fuels, and improved cylinder cooling.

(4) The development by the Army, the Navy, and the industry of satisfactory controllable-pitch propellers.

(5) The development by the Committee of new and more efficient wing sections.

(6) Improved streamlining and use of wing flaps, assisted by the Committee's researches.

A great increase in the high speed of an airplane would ordinarily be accompanied by a dangerous increase in its landing speed. This presented a problem of devising means of increasing the lift and drag of the wing to permit landing at a lower speed, without attendant loss of control. Increased safety in the operation of aircraft will result primarily from reduction in landing speeds with retention of adequate control. Toward this end the Committee has conducted researches on a number of high-lift devices, some of which are now in use. Others under investigation hold promise of further progress in retaining adequate control at lower landing speeds.

Research pays.—It is essential to national defense and to American air commerce that the United States strive to keep abreast or ahead of other nations in the technical development of both military and commercial aviation. The researches of the Committee lead to material improvement in the performance, efficiency, and safety of aircraft. No money estimate can be placed on the value of superior performance of aircraft in warfare, for aerial supremacy is quite likely to be ultimately decisive of a war; nor can a money estimate be placed on the indeterminable savings in life and property due to improved safety in the operation of both military and civil aircraft. The value in dollars and cents of improved efficiency in aircraft resulting from the Committee's work can, however, be fairly estimated. For example, the results of six researches completed by the Committee within the last few years, when applied to airplanes equal in number to those in use during 1932, show that savings in money alone will be made possible in excess annually of the total appropriations for the Committee since its establishment in 1915.

In the opinion of the Committee the continued development of aviation is vital to our national security and defense. Aviation is also becoming an increasingly important factor as an agency of transportation. Its continued development holds possibilities for the growth of a large industry, creating new sources of wealth, new fields of employment, and new outlets for the energies of the American people. The Committee is of the opinion that the most essential fundamental activity of the Government in aeronautics is the continuous prosecution of well-organized and coordinated scientific research. Continuous fundamental research is absolutely vital in the last analysis, as it underlies the effectiveness of the air arms of the national defense, the stability of the aircraft industry, and the prospect of ultimate success of air transportation upon a sound economic basis. The Committee accordingly recommends continuation of its work in the fields of pure and applied research on the fundamental problems of flight.

PART I

REPORTS OF TECHNICAL COMMITTEES

In order to carry out effectively its principal function of the supervision, conduct, and coordination of the scientific study of the problems of aeronautics, the National Advisory Committee for Aeronautics has established under the executive committee four main technical committees—the committees on aerodynamics, power plants for aircraft, materials for aircraft, and problems of air navigation—and under these committees, eight subcommittees. These technical committees prepare and recommend to the executive committee programs of research to be conducted in their respective fields, and as a result of the nature of their organization, which includes representation of the various agencies concerned with aeronautics, they act as coordinating agencies, providing effectively for the interchange of information and ideas and the prevention of duplication. The membership of these committees and subcommittees is listed in part II.

The committees on aerodynamics and power plants for aircraft have direct control of the aerodynamic and aircraft-engine research, respectively, conducted at the Committee's laboratory at Langley Field, and of special investigations conducted at the Bureau of Standards. The greater part of the research under the supervision of the committee on materials for aircraft is conducted by the Bureau of Standards. The experimental investigations in aerodynamics, aircraft power plants, aircraft materials, and air-navigation problems undertaken by the Bureau of Aeronautics of the Navy, the Army Air Corps, the Bureau of Standards, and other Government agencies are reported to these four committees.

REPORT OF COMMITTEE ON AERODYNAMICS

SUBCOMMITTEE ON AIRSHIPS

In order that the committee on aerodynamics may be kept in close touch with the latest developments in the field of airship design and construction and that research on lighter-than-air craft may be fostered and encouraged, a subcommittee on airships has been organized under the committee on aerodynamics.

The subcommittee has kept in close touch with the airship investigations under way at the Langley Memorial Aeronautical Laboratory. The program of airship work at the laboratory includes the study in the full-scale wind tunnel of the forces on a large airship model at large angles of pitch and of yaw. In cooperation with the Bureau of Aeronautics of the Navy, the Committee has also obtained information on the speed and deceleration on the full-size airship *Macon.*

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

Landing Speed and Speed Range.—The speed of both military and commercial airplanes has increased very markedly during the past year. This increase in speed has been accomplished partly through an increase of engine power, but mainly through the reduction of drag. The low drag, while advantageous in obtaining high speed, is disadvantageous in that it limits the gliding angle which can be obtained at low speed, and makes necessary a very long flat approach to a landing. The higher maximum speeds have also been accompanied by a tendency to use heavier wing loadings, and the landing speeds have increased to what seems to be the practical limit. Under these adverse landing conditions, devices for increasing the maximum lift coefficient and also the drag at the high angles of attack have been of great interest.

Flap modifications.—The committee's work on split flaps has been continued during the past year. These flaps have now been used on several airplanes, either in the simple form or in the Alfaro-Zap form, in which the flap is moved to the rear as well as deflected downward. In response to the demand for more detailed information in regard to their aerodynamic effect and in regard to the air loads on the flaps, further tests have been made in the 7- by 10-foot wind tunnel. The air loads on the flaps have been measured for the purpose of supplying information on which to compute the structural strength needed and the forces required to deflect them (report in preparation). The results of these tests showed that the division of the total lift between the split flaps and the wing was little affected by flap deflection in the ordinary flight range, although the division of the total drag was greatly affected by flap deflection. The normal-force coefficient was also greatly affected by flap deflection, the coefficient for the flap alone reaching a value of approximately 1.40 at the angle of attack and flap deflection for maximum lift.

Another investigation was made in the 7- by 10-foot tunnel to determine the effect on the aerodynamic characteristics of partial-span split flaps located at various positions along the wing span (Technical Note No. 472). The results showed that as the flap is cut away from the tip, the loss in lift is small at first, but becomes substantial if sufficient flap is removed to allow room for ordinary ailerons. If the flap is cut away from the center, the loss starts more rapidly, being in the neighborhood of 8 or 10 percent for the cut-out usually found necessary for structural reasons.

Full-scale tests with simple split flaps have been made with a parasol monoplane both in the full-scale tunnel and in flight, with flaps 20 percent of the wing chord in width extending over the outer 90 percent of the wing span. The full-scale lift, drag, and pitching-moment coefficients for the airplane were found in the full-scale tunnel both with the horizontal tail surfaces in place and with them removed (Technical Note No. 475). The value of $C_{L_{max}}$ was increased from 1.47 to 2.09 by deflecting the flap, the stalling angle being the same in both cases. These results agree well with the model results obtained in the 7- by 10-foot tunnel with regard to the effect of the flap. The computed landing speed of the airplane was reduced from 51 miles per hour to 41.9 miles per hour by the use of the flaps.

The flight tests, the model tests in the 7- by 10-foot tunnel, and the full-scale wind-tunnel tests all showed that the control force required to displace a simple split flap is undesirably great. A series of wind-tunnel tests is now in progress to study the effectiveness of various methods of reducing the hinge moments of these flaps.

A year ago the highest lift coefficient obtained by the Committee with any kind of flap device was 3.17, obtained with the Fowler flap. During the past year attempts have been made to obtain still higher lift coefficients. First, a slot was added to the leading edge of the Fowler-type wing, but only a slight increase in lift coefficient resulted. A special slot having a slat of good airfoil section was then developed and this in its best location gave a maximum lift coefficient with the Fowler-type flap of 3.62 (Technical Note No. 459). Then still another slot was added, a fixed slot near the trailing edge of the basic wing, which gave a slight additional increase to 3.76, a total increase of about 200 percent above the value for the wing with all devices retracted. The investigation of the plain Fowler-type flap is being continued in the 7 by 10 foot wind tunnel to find the relative characteristics with Fowler flaps of various sizes and to determine the loadings on the flaps.

Wind-tunnel tests have also been made with a flap consisting of an auxiliary airfoil pivoted at the rear of the main wing as proposed by Wragg. The auxiliary airfoil is located so that a slot is formed between the two wings in a manner somewhat similar to that of the Fowler-type flap, but the auxiliary is not retracted into the main wing. This arrangement with a 15 percent auxiliary airfoil gave a maximum lift about the same as that obtained with a simple split flap.

Fixed auxiliary airfoils.—Last year a fixed auxiliary airfoil had been developed which gave an increased lift coefficient and an increased speed range, and which was thought advantageous particularly because it had no moving parts (Technical Report No. 428). Flight tests were made with the auxiliary airfoil mounted on a small parasol monoplane (Technical Note No. 440). At that time the investigation had included only one size of auxiliary airfoil and only one auxiliary airfoil section. The results seemed sufficiently promising to make it worth while to test auxiliary airfoils of other sizes and airfoil sections, and several sizes with three different sections have now been tested in a sufficient number of positions with respect to the main wing to determine the best arrangement (Technical Report No. 472). None of these has been found to be definitely superior in all respects to the original, although a decidedly lower minimum drag was obtained with a symmetrical section. The highest values of the maximum lift coefficients and the speed range criterion, $C_{L_{max}}/C_{D_{min}}$, were obtained with auxiliary airfoils with chords 11 to 15 percent of the main wing chord, although those as small as 7.5 percent of the main wing chord gave nearly the same values as the larger sizes.

Tailless airplanes.—Wind-tunnel tests were made of a model wing having an aspect ratio of 3 and a tapered plan form with a straight trailing edge (Technical Note No. 463). The Clark Y airfoil section was used throughout the entire span, with no washout. A constant-chord trailing-edge flap was used for longitudinal balance and control moments. The simple wing with no washout or change of basic section along the span had aerodynamic characteristics well suited for use on tailless airplanes. A higher lift coefficient was obtained with the full-span flap deflected as a unit to give longitudinal balance than with either the inner or outer portions of the flap deflected separately. Further tests are being made with the same basic model having a fixed auxiliary airfoil mounted ahead of the leading edge for the purpose of increasing the maximum lift coefficient and improving the balance characteristics.

Controllability.—The Committee's work on lateral control has been continued during the past year along two main lines. First, the search has been continued for a lateral-control device that is completely satisfactory throughout the entire speed range, including angles of attack above the stall. More recently the work has been concentrated on lateral-control devices suitable for wings equipped with flaps or other high-lift devices along their entire spans. During the past year some of the control devices that the wind-tunnel investigation showed to be promising have been tried on an airplane in flight, with the result that considerable information has been obtained about the characteristics to be desired in a good lateral-control device, but it was found that each of the single lateral-control devices when tested in flight had at least one undesirable feature. One interesting point brought out by the flight and wind-tunnel tests was that the yawing effect of the ailerons as observed by the pilots corresponded to the yawing moments as measured about wind axes, and not about body axes as had previously been thought. The flight tests also brought out the fact that the yawing moments caused by the ailerons are relatively unimportant in cruising and in high-speed flight, but are of critical importance at the angles of attack near and above the stall.

Conventional ailerons.—The investigation in the 7- by 10-foot wind tunnel has been extended to include conventional ailerons of various shapes and sizes, with differential movements and with balance arrangements, on wings of various plan forms (Technical Reports Nos. 419, 422, 423, and 444, and Technical Notes Nos. 445, 449, and 451). In all the tests the ailerons of wide-chord and short-span dimensions gave reasonably high values of rolling moment at the high angles of attack definitely above the stall, whereas the narrower ailerons gave substantially lower values above the stall. It therefore seemed that the short wide ailerons might give at least fair control at angles of attack above the stall. The wind-tunnel tests showed, however, that while some conventional aileron arrangements had positive yawing moments with respect to the body axes, all gave adverse yawing moments with respect to the wind axes at high angles of attack, regardless of the differential motion, or of such balancing arrangements as the Frise type. When tested in flight none of the conventional ailerons, whether of long narrow or of short wide form, regardless of the differential motion used, gave control above the stall. From these results it seems that with conventional ailerons the secondary features, the adverse yawing moments, and the aggravation of the stall by the down-going aileron over its portion of the wing, become more important at high angles of attack than the direct rolling moment given by the ailerons.

Wind-tunnel tests have been made with conventional ailerons on a slotted wing (Technical Note No. 443), and flight tests have been made on the lateral-control characteristics of a low-wing monoplane equipped with both slots and flaps, the flaps being confined to the inner portion of the span to allow room for conventional slotted ailerons (Technical Note No. 478). The results of these tests showed that the rolling-moment coefficients obtained were about the same regardless of whether the slots were open or closed, or whether the flaps were up or down, all of which is in accordance with the results of the wind-tunnel tests. In fact, the rolling moments measured in flight agreed very well with the rolling moments measured on similar ailerons under static conditions in the wind tunnel when the rolling action of the airplane was taken into account in the computations.

If conventional ailerons are used on wings with flaps, whether of the plain or split variety, a part of the span of the flap must in most cases be sacrificed. One arrangement has been devised in which ordinary ailerons are used with a full-span split flap by retracting the flap into the wing ahead of the ailerons. With this arrangement, in order to bring the flap into the most favorable position when deflected it is moved to the rear as well as downward. Wind-tunnel tests have shown that reasonably satisfactory rolling and yawing moments are obtained by the conventional ailerons with the flap deflected. With the flap retracted the conventional ailerons operate in the normal manner. A special wing having this arrangement is now being fitted to a parasol monoplane for flight tests.

External ailerons.—A wind-tunnel investigation has been completed on external ailerons composed of separate airfoils attached to but apart from the main wing. The external ailerons were tried in positions all around the main wing, but particularly in four regions: (1) In front of and below the leading edge; (2) above the nose portion; (3) above the trailing edge; and (4) below the trailing edge of the main wing. The ailerons in front of and below the leading edge were found to give reversal of control at low angles of attack. In the region above the forward portion of the wing the ailerons had rolling and yawing moment characteristics somewhat similar to those of spoilers, the rolling-moment coefficients increasing in magnitude as the angle of attack was increased to and through the stall. For the ailerons above the trailing edge the characteristics were similar to those of conventional ailerons except for the yawing moments, which were better. When mounted behind and below the trailing edge, the external ailerons could be used as lift flaps if deflected downward together. If deflected differentially they acted like ordinary ailerons with unusually large adverse yawing moments.

The most favorable location for control at high angles of attack up to well above the stall appeared to be just above the nose portion of the main airfoil, a short distance back from the leading edge. Flight tests have been made on external ailerons in this position with two different types of deflection, in both of which the ailerons were moved one at a time. With one type of deflection the trailing edge was moved up only, and with the other type the trailing edge was moved down only, these opposite deflections being selected because the wind-tunnel tests showed that moving the aileron in either direction from a critical neutral position reduced the lift on the adjacent portion of the wing.

When tested in flight these ailerons had a lag, or delayed action, when given the deflection in which the trailing edge was moved downward, but they were free from lag when the trailing edge was given the individual upward deflection. In the ordinary flying range the acceleration in roll was found to be only about half as great as that obtained with ordinary ailerons of approximately the same size, but the final rate of roll was greater than that obtained with ordinary ailerons. The latter condition was not considered advantageous by the pilots. The ailerons gave moderate control at the angles of attack above the stall. As has been found with all external ailerons tested in flight, however, the control force was high at the high speeds, even with the aileron hinge axis moved as far back as possible without resulting in overbalance at low speed. The work dealing with external ailerons is still in progress and the reports of the tests are not yet completed.

Floating tip ailerons.—A wind-tunnel investigation has been completed of floating tip ailerons having various airfoil sections, hinge axis locations, and end-plate arrangements, on rectangular wings; on straight wings with single and multiple floating tip ailerons of narrow chord; and on tapered wings with 2° of taper (Technical Report No. 424 and Technical Note No. 458). In general, the floating tip ailerons gave reasonably satisfactory values of rolling moment at all angles of attack, practically zero values of yawing moment about wind axes, and a reduction in the unstable autorotational moments, but they also gave poor airplane performance characteristics, especially in regard to climb. The most promising of the floating tip ailerons seem to be those on wings of extreme taper. In this case, very light control forces are required and it would seem that there should be no great reduction in airplane performance if the span of the fixed part of the wing is sufficient for the rate of climb desired.

Upper-surface ailerons.—These ailerons are used with split flaps and are formed by deflecting the upper trailing-edge portions of the wing above the split flaps. They are deflected upward individually. Both wind-tunnel and flight tests showed that, while moderate rolling control can be obtained at angles of attack below the stall with the flap either deflected or retracted, if simple unbalanced upper-surface ailerons are used the control forces required are excessively high even though the ailerons have a narrow chord. Reports on both the wind-tunnel and flight tests are in preparation. Work is now being carried on in the 7- by 10-foot tunnel to investigate the possibility of obtaining a suitable reduction of hinge moment by means of proper hinge location and aileron profile.

Spoilers.—Various spoiler arrangements have been tested both in the wind tunnel (Technical Note No. 415 and Technical Report No. 439) and in flight (report in preparation). These spoilers consisted essentially of plates and surfaces arranged to project from the upper surface of a portion of the wing in order to reduce the lift over that portion. The spoilers located near the nose of the wing gave control at angles of attack above the stall, but, unfortunately, below the stall they had a definite lag or delayed action due to an initial but imperceptible tendency to roll in the wrong direction. The time from the deflection of the control to the start of the roll in the desired direction averaged about one half second. The lag was found in flight with each of the three forms of spoiler tested, the first being a flap set in the upper surface and hinged at the front edge, the second a retractable spoiler projecting out through a slot in the upper surface of the wing, and the third the retractable spoiler cut to saw-tooth form. These results seem to eliminate the simple spoiler located in the forward portion of the wing as a satisfactory lateral-control device when used by itself, but, if control above the stall is of sufficient importance, a satisfactory arrangement free from lag can apparently be obtained by the proper combination of spoilers and ordinary ailerons. The spoilers can be arranged to reduce the aileron hinge moments if desired, either by means of their location or their connecting linkage.

In regard to control at angles of attack above the stall, the flight tests have shown that the lateral instability above the stall may be so violent as to eliminate the possibility of handling the airplane satisfactorily even with an effective lateral control. Considering this condition it seems that even for occasional emergency use control above the stall may be of slight value unless it is accompanied by stability.

If the spoilers are moved sufficiently far back along the chord of the wing there is no doubt that the lag can be eliminated. Unfortunately, as the spoiler is moved back its effectiveness in giving control at angles of attack above the stall is lost. The present plans are to continue flight tests to find the most forward spoiler location free from lag. Tests are now under way with the retractable-type spoilers near the trailing edge of the wing. In this position they might well be called "retractable ailerons", for they give approximately the same rolling and yawing moments as the upper-surface ailerons but with the advantage of very low control forces, for with this device the hinge moments can be made practically zero.

Aerodynamic balancing of control surfaces.—Considerable interest has been centered during the past year on means of balancing the forces required to operate the various control surfaces of an airplane. An investigation has been made in the 7- by 10-foot tunnel on a model wing with ailerons and balanced surfaces of various kinds. Hinge moments and rolling and yawing moments, as well as the general performance with the various arrangements, were measured. One type of balancing arrangement investigated consisted of flat plates or tabs attached to the trailing edge of the ailerons and deflected various amounts. Another type of tab was formed by deflecting the trailing-edge portion of the aileron itself. The latter type proved more effective and complete servo-control could be obtained for moderate aileron deflections when the inset tab was 20 percent of the aileron chord and covered the entire aileron span. The hinge moments for large aileron deflections, however, were greater with the tabs than without. Further work is in progress with inset tabs and horn-and-paddle-type balances on ailerons, and with inset tabs on rudders and elevators also.

Stability.—A theoretical study of stability, based on the theory of small oscillations, is being made with a view to making possible the rational prediction of the stability characteristics of an airplane by simple means.

Effect of wing-tip shape.—A wind-tunnel investigation of the effect of wing-tip shape on lateral stability is in progress. Tests have been made with tips having rectangular and curved plan forms, and with the tip in front curved upward and downward different amounts. The tests include 6-component force and moment measurements at several angles of yaw, as well as rotation tests at zero yaw. The results show the effect of tip shape on general performance and on four of the lateral-stability factors—damping in roll, and variation of the rolling moment, yawing moment, and cross-wind force with sideslip. It was found that the rectangular tips gave higher values of the rolling and yawing moments due to sideslip than the curved tips, while the damping in roll was about the same for all of the tips tested.

Effective dihedral.—A detailed wind-tunnel investigation is being made to determine the effects of dihedral on lateral stability and on general performance. In the 7- by 10-foot wind tunnel tests are being made with wing models having various amounts of the span deflected upward to give dihedral. The results obtained to date indicate that a dihedral angle only in the outer 25 percent of the wing is quite effective in producing rolling moments due to sideslip up through large angles of attack. In addition to the wind-tunnel investigation qualitative flight tests are being made in which the lateral stability is being found for a parasol monoplane with dihedral angles ranging from 0° to 9°.

Landing.—The cinematographic apparatus developed for studying the motion of airplanes in flight close to the ground, particularly in landings, has been utilized in an investigation of glide landings in gusty air. The airplane used in this investigation was equipped with unusually long shock-absorber struts. In the tests with the elevator held stationary, for the worst case recorded the attitude of the airplane varied from 14° nose up to 9° nose down, and the rate of descent varied from 28 feet per second to 4 feet per second, while the airplane was descending from 550 feet to 350 feet. At the present time a paper is being prepared in which the results of this investigation will be presented, together with the results of an investigation of the variation in wind speeds close to the ground.

The above-mentioned apparatus has also been used in investigations of the relative efficiency of two types of long-stroke shock-absorber struts, and of the landing characteristics of an autogiro. The latter investigation was undertaken at the request of the Aeronautics Branch, Department of Commerce, to provide data for use in the formulation of design rules.

Take-off.—A comparatively simple method of calculating the length of take-off run has been developed from the assumption of a linear variation in net accelerating force with air speed. This method has been published during the year in Technical Report No. 450.

A flight investigation was made to determine the effect of automatic slots and plain flaps on take-off, the tests being made with a small low-wing monoplane. The take-off run was materially reduced with slots but not with flaps, the magnitude of the effects being dependent to some extent on the gross weight. The difference in the effects of the two devices lay principally in the fact that the flaps increased the drag throughout the take-off run and thereby retarded the acceleration, whereas the slots had no appreciable deleterious effect during the preceding ground run.

Further information on the effect of flaps on take-off run is available from tests in the full-scale tunnel on a small parasol monoplane. Calculations based on the power characteristics with a 95-horsepower engine and a fixed-pitch propeller indicated that a slight reduction in the calculated take-off run would be obtained with a flap depression of about 27°, but because of the poor climb with the flaps down, the total take-off distance required to clear an obstacle 100 feet high would be greatly increased for flap settings greater than 20° and would not be appreciably improved by lower settings.

In an attempt to calculate the take-off run from known airplane and propeller characteristics it was found that no one value for the coefficient of ground friction would give satisfactory agreement with the experimental data for all take-off conditions. A study is being made of the influence of various factors on take-off.

The recent perfection of several types of controllable propellers has increased the interest in methods of computing the possible performance of such propellers. A report has been prepared pointing out some of the methods to be used in such calculations making use of data previously published by the Committee. The report (Technical Note No. 484) also shows the possibility of increasing the performance of some airplanes.

In the computation of the propeller performance of airplanes, particularly of seaplanes, it has been found that the information previously published in Technical Report No. 350 was not complete enough in the low-speed range for the calculation of the available thrust of the propeller. The original data have been recomputed, a new coefficient being used, and the results are being presented in a new report in the form of charts which will be useful to designers in computing the low-speed characteristics of propellers.

When retractable landing gears are used on a low-wing monoplane the question arises how the lift coefficient of the wing is affected by the open wheel wells in the lower surface of the wing when the landing gear is extended and how the time for taking off may be affected. In order to furnish information on this point, the Committee was requested by the Army Air Corps to make tests in the full-scale tunnel on a Lockheed Altair airplane. It was found that the wheel openings in the lower side of the wing have a negligible effect upon the lift and take-off of the airplane. The results are given in Technical Note No. 456.

MANEUVERABILITY.—A report on the maneuverability of an observation airplane, an investigation undertaken at the request of the Bureau of Aeronautics, Navy Department, has been published (Technical Report No. 457). Consideration has been given to the development of a criterion for maneuverability based on the results of previous tests.

SPINNING.—Intensive research on the problem of the spin has been continued both in flight and in the vertical tunnel, the latter having been in regular operation throughout the past year (Technical Report No. 456). Attention has been concentrated largely on the factors affecting the steady spin and recovery from it, for the ultimate purpose of insuring in the design of airplanes that proper recovery will be obtained, or that the steady spin will be entirely prevented.

A paper has been published on the effect of sharp leading edges on the spin (Technical Note No. 447). There has also been published a paper (Technical Note No. 468) on the results of a study of the influence of the various factors affecting the steady spin. In this study the predicted influence of various modifications in airplane design features were correlated with the results of flight tests as reported from numerous sources. An analysis of the results obtained in a flight investigation conducted on a small biplane, of the effect of control setting and mass distribution on the steady spin, has been completed and a paper on this subject is now being prepared. It was found that in general the observed effect of extensive changes in mass distribution could be predicted by utilizing the knowledge already available from previous theoretical and experimental studies of the problem.

There are rather conclusive indications that provision of sufficient damping yawing moments offers the most effective method of eliminating bad spinning characteristics, and several researches designed to provide additional information on the amount of yawing moment desired and the method of securing it effectively have been carried out or are now in progress. An investigation conducted in the vertical tunnel to determine the effect on spinning characteristics of locating the stabilizer and elevator in several fore-and-aft positions and also in two vertical positions has been completed and a paper on the results has been published (Technical Note No. 474). The results indicate that a very favorable increase in yawing moment is obtained by a high and/or a rearward position of the horizontal tail surfaces.

In the same connection the spinning characteristics of a biplane of the fighter type have been investigated in flight with various modifications to improve the effective fin area. In its original condition this airplane would occasionally fail to recover when the controls were manipulated in accordance with the normal procedure for recovery. The character of the spin was first improved to an extent that made it safe for spinning by the addition of considerable fin area above the fuselage, a modification that could be readily incorporated in the existing airplanes of that type. The investigation was then continued to determine the effect of raising the stabilizer, a modification that was expected to prove very beneficial, on the basis of previous studies in the vertical tunnel. In tests now completed a very marked improvement in the character of the spin has been brought about by raising the stabilizer to the top of the vertical fin. At the present time the effect of an intermediate stabilizer position is being investigated, such a position being more readily adaptable to structural design requirements than the extreme upper position.

The flight investigation with this airplane has been very closely correlated with tests in the vertical tunnel on a model of the same airplane primarily for the purpose of determining the extent to which agreement might be expected between model and flight spinning tests, and possibly of deriving factors for converting model spinning results to full scale. The model data have not yet been completely analyzed.

A third research concerned with the yawing moments contributed by various parts of the airplane in spins is now being carried out in flight on a small biplane previously used for mass-distribution studies. The lateral forces on the fin, rudder, and fuselage are being determined by pressure-distribution measurements, and at the same time the spinning motion is determined so that resultant moments can be computed. The yawing moment developed by the remainder of the airplane, chiefly the wings, is then found.

At the request of the Army Air Corps, three models of special pursuit airplanes were tested in the vertical tunnel for prediction of their spinning characteristics. It is interesting to note that the characteristics as measured compared favorably with what had been predicted on the basis of previous tests with other models on the spinning balance.

An experimental method for determining the moments of inertia of airplanes for use chiefly in spinning studies has been used by the Committee for several years. Essentially, the method consists in suspending the airplane so that it can oscillate as a pendulum. Refinements in the method have been made from time to time, some of them being of fundamental importance. A report has been published (Technical Report No. 467) describing the procedure followed in these experiments, particularly the method employed in correcting for effects of the ambient air.

AERODYNAMIC INTERFERENCE AND DRAG.—The broad basic investigation of aerodynamic interference and drag previously undertaken has been continued through the year. The investigation is intended to determine where and under what conditions interference effects may be of importance, and how adverse interferences between airplane parts may be reduced and favorable interferences utilized. The work is advantageously divided among various sections of the laboratory.

Wing-fuselage interference.—An extensive investigation dealing largely with interference effects between the fuselage and the wing has been in progress during the year in the variable-density wind tunnel. The tests are made at a high value of the Reynolds Number, and deal with combinations of variously shaped fuselages and wings in different relative positions. A large part of the test program has been carried out and the results are being analyzed, but the investigation has not progressed sufficiently far to warrant the drawing of conclusions.

The best means of determining interference effects is by measurements on actual airplanes in the full-scale wind tunnel where the tests can be made with and without the slipstream, and where flow surveys can be made behind the airplane. Two investigations of this nature have been undertaken during the year. Wing-fuselage interference and buffeting were investigated on a low-wing monoplane displaying excessive drag and tail buffeting at high angles of attack, successive modifications being made, including the addition of variously formed fillets at the juncture of the wing and fuselage, the installation of a National Advisory Committee for Aeronautics engine cowling, the use of short-span auxiliary airfoils, and provision for reflexing the trailing edge of the wing. Preliminary results of this investigation have been published in Technical Note No. 460.

A more complete report is in preparation in which will be shown surveys of the flow about the tail surfaces with and without power and with the various modifications mentioned. A special survey apparatus described previously was used for this work. It was found that the fillets, either alone or in combination with the National Advisory Committee for Aeronautics cowling, reduced the buffeting and interference to unobjectionable magnitudes at angles of attack up to the stall. The best results were obtained by the use of fillets together with the National Advisory Committee for Aeronautics cowling.

Another full-scale investigation of wing-fuselage interference on a YO-31A airplane is in progress in the full-scale tunnel. A mock-up of this airplane, which was originally built with a gull wing, has been arranged for the installation of wings in three positions representing a high-wing, a mid-wing, and a low-wing monoplane and in the latter position a full cantilever wing will be tested as well as the braced wing used in the other positions. Both force tests and pressure-distribution measurements will be made for the whole series of tests and these, taken with air-flow measurements at the tail and engine power data, will give a complete picture of the effects of wing-fuselage interference on this particular airplane. The part of the investigation dealing with the gull wing has now been completed and the results are being analyzed while the next wing arrangement is being set up.

Wing-nacelle propeller research.—The extensive program of research on the mutual influences of wing, nacelle, and propeller has been continued in the propeller-research tunnel. Investigation of nacelles with tandem propellers, of nacelles with pusher propellers, and of nacelles with tractor propellers on biplane wings has been completed. A large number of supplementary tests correlating these investigations with the investigations of tractor propellers on nacelles and monoplane wings have also been made. Reports covering these various parts of the investigation are now in preparation.

The effect of the shape and size of the wing on the mutual interference has been investigated by means of tests on a wing of Clark Y section and smaller chord for comparison with the earlier tests with a thick wing of large chord. Results of this investigation have been published as Technical Report No. 462. The general conclusion drawn from the investigation is that a completely cowled tractor nacelle located ahead of the leading edge of the wing is the best arrangement. The tandem-nacelle arrangement suffered largely from the high drag of the engine nacelle. The same is true of the pusher nacelle arrangement; in fact, the pusher part of the nacelle or nacelle adjacent to the pusher propeller appears to be the undesirable feature in both the pusher and tandem arrangements. None of these arrangements approaches the efficiency of the best tractor-nacelle arrangement. There appear to be good grounds for supposing that an arrangement consisting of an engine located ahead of the leading edge of the wing in a National Advisory Committee for Aeronautics cowled nacelle and an extension shaft carried to the trailing edge of the wing with the propeller located at the end will have high efficiency. Tests are soon to be made with this arrangement.

Most of the preceding tests have been made with nacelles for air-cooled radial engines. The liquid-cooled airplane engine has not been overlooked; some tests have been made to determine the propulsive efficiency and the interference effects of a liquid-cooled engine nacelle and a wing. The tests made thus far indicate that the largest drag-producing component of the nacelle of the ordinary type is the radiator, which is normally exposed below the nacelle. A test was also made with a radiator completely surrounding the engine and enclosed within a nacelle of circular cross section, giving an outward shape similar to that of an air-cooled engine nacelle. The results of this test indicated that the drag of the usual liquid-cooled installation could be considerably reduced by such an arrangement.

The great mass of data obtained on wing-nacelle-propeller effects in the propeller-research tunnel was obtained on wings of 15-foot span, aspect ratio 3, with a propeller of 4-foot diameter. If the propeller-nacelle interference extends more than about two diameters outboard of the thrust axis, then the effect is incompletely measured on such a small-span wing. In order to check this possibility, the same nacelle-propeller combination has been tested in the full-scale wind tunnel in three positions relative to a wing of the same chord and section whose span was progressively decreased from 30 to 25, to 20, and finally to 15 feet. Forces, propeller characteristics, and pressure distribution were measured and a preliminary comparison shows the effect of span to be not so large as to invalidate the test results on short spans. The results of these tests in the full-scale tunnel are being prepared for publication.

Drag of landing gears.—It has been realized for some time that the drag of the landing gear constitutes in many cases a large part of the total drag of the airplane. That manufacturers of airplanes are cognizant of this fact is witnessed by the numerous installations of retractable landing gears in recent airplanes. The additional weight and the mechanical complexity have retarded the general adoption of retractable landing gears. That these difficulties are being surmounted is attested by the numerous installations of retractable gears in recent designs, but the use of nonretractable gears in several high-performance airplanes indicates the need for more information on the possibilities of reducing the drag and the unfavorable interference effects.

An investigation of the drag of landing gears has recently been completed in the propeller-research tunnel. In this investigation a full-size airplane fuselage was mounted on the balance and a large number of landing gears were attached to this fuselage and the drag determined. The drag of the complete landing gear as thus determined was supplemented by tests on component parts which were made in the 7- by 10-foot wind tunnel (Technical Report No. 468). About 20 types of landing gears were investigated which, with numerous variations, brought the total number of tests to over 100. A number of styles of wheels and wheel fairings and fairings between wheels and struts were tried, so that the whole research constituted a fairly complete study of landing-gear effects. The final report including analysis and design studies has been completed.

It was found that landing gears of the older types without any particular streamlining and having very high drag can be greatly improved by installing fillets between the struts and wheels and fairings over the wheels. Of the newer types, the cantilever-type gear had a fairly low drag but the lowest drag was obtained with a gear protruding vertically below the wing and completely faired in. With this type the drag was reduced to about 13 pounds for the landing gear at 100 miles an hour. It was also found that, as far as drag is concerned, the various types of wheels, such as high-pressure, low-pressure, and streamlined wheels, have relatively small effect on the total drag, but that interference effects between wheels and adjacent members is much more important. Taken all together, it appears that the drag for the exposed landing gear can be reduced to a point where its effect even on the high-performance airplane will be relatively small and the consequent complication of retractable gears can be avoided in a number of instances.

Cowling.—The very general adoption of the National Advisory Committee for Aeronautics cowling and its importance for high-speed flight have pointed to the desirability of further research to establish more trustworthy design data. An extensive systematic investigation has accordingly been undertaken, consisting of three parts: (1) the cooling requirements of an air-cooled engine, to be established by the power plants division; (2) the best cowling arrangement to obtain the necessary cooling with minimum drag, to be established by model tests in the 7- by 10-foot tunnel; (3) verification of the results from parts (1) and (2) by cowling tests on full-size engines in the propeller-research tunnel.

Part (1) is in progress by the engine research division. Part (2) is in progress in the 7- by 10-foot tunnel, and includes the effect of changes in the front opening, the rear opening, the size of the nacelle, the camber of the leading part of the cowling, and the effect of different types of leading edge. The investigation has not been carried far enough to warrant definite conclusions.

Propeller drag.—For those airplanes whose functions require that they be dived at terminal velocity, the accurate prediction of this velocity is of importance. Since the propeller may offer considerable drag in fast dives and since it exerts a controlling influence on the engine speed, the Committee was requested by the Bureau of Aeronautics, Navy Department, to make an investigation to determine the quantitative nature of these effects to the end that precise estimates of the terminal velocity could be made. This investigation included flight dive tests and wind-tunnel propeller tests. During the past year the information has been analyzed and a report prepared (Technical Report No. 477), which presents the results in a form readily usable for the quantitative determination of the influence of the propeller on the terminal velocity and engine speed. Some of the propeller tests were extended to include the negative thrust range of operation applicable to this condition of flight, and the results have been given in Technical Report No. 464.

Use of the smoke tunnel and the high-speed tunnel.—The smoke tunnel and the high-speed tunnel have been employed in connection with interference studies. Investigations in the smoke tunnel, however, have been made primarily to study its utility for such researches. For example, the air flow was examined about a model on which was simulated a windshield of the forward-sloping V-type as used on some transport airplanes. Observations of the smoke flow indicated a large wake. The windshield was then altered until a form was reached which gave a more satisfactory flow. The actual drags of the original and final windshields were then compared by tests at a large value of Reynolds Number in the variable-density tunnel. The results confirmed the deductions from the observations in the smokeflow tunnel in that they showed the original windshield to have an excessive drag and the final form less than half that of the original.

Another investigation of particular interest was started in the smoke tunel and continued in the high-speed tunnel. In the smoke tunnel the flow about a streamline wire (lenticular section) model was observed to indicate a relatively high drag. The flow was found to be improved by the addition of small round wires on the surface of the streamline wire to form a longitudinal protuberance on either side of the section contour somewhat behind the leading edge. Various sizes and positions of the protuberance were investigated. Later the investigation was continued in the high-speed tunnel where full-scale wires could be tested at full speed, and the drag accurately measured. A streamline wire of nominal size, 0.5 inch with round wires of 0.003-inch diameter soldered along its surfaces to form the protuberance, at certain speeds showed a drag reduction due to the protuberances of more than 40 percent.

Effects of surface roughness.—The question sometimes arises as to the effect of surface roughness on the aerodynamic characteristics of a wing, and two investigations of a minor nature have been conducted on this subject during the year. Tests were made in the variable-density wind tunnel on a number of airfoils of the National Advisory Committee for Aeronautics 0012 section on which the character of the surface was changed from a rough to a very smooth finish. Measurable adverse effects were found to be caused by small irregularities in airfoil surfaces which might ordinarily be overlooked. These results were published in Technical Note No. 457.

An investigation of the effect of rivet heads on the characteristics of a 6- by 36-foot Clark Y metal airfoil was carried out in the full-scale tunnel and the results published in Technical Note No. 461. The effect of conventional brazier-head rivets on the drag of the wing was found to be large, and an investigation of various types of flush rivets is next to be undertaken.

AIRFOILS.—*Theory of wing sections.*—A report on the aerodynamic potential theory of wing sections (Technical Report No. 452) has been prepared in which is presented a unified rigorous treatment of the general theory of monoplane wing sections of any shape. The numerous special cases that have been previously treated in the aerodynamic literature are reduced to special cases of the general theory, which permits a clearer perspective of the entire field of wing theory. A comparison of the predicted theoretical pressures with experimental work for the National Advisory Committee for Aeronautics M6 airfoil at 12 different angles of attack presents a striking illustration of the value of the theory. In a later report (Technical Report No. 465) application of the general theory is made to 20 conventional or selected airfoils. The theoretical distribution of pressure at lift coefficients of 0, 0.5, 1.0, and 1.5 is presented graphically. Analysis and discussion of the results show clearly that many of the aerodynamic properties and characteristics of airfoils are explainable and predictable on the basis of the theoretical pressure-distribution curves.

Investigation of airfoil shape.—The systematic investigation of airfoil characteristics as affected by variations of the airfoil shape has been continued in the variable-density tunnel and a report (Technical Report No. 460) has been prepared covering the tests under comparable conditions of 78 related airfoils.

The tests were made primarily to investigate airfoil characteristics as affected by variations of the section thickness and the mean-line form. One of the objects of investigating a wide variety of related airfoils, aside from supplying data to facilitate the choice of the most satisfactory airfoil for a given application, was to determine the trends with changes of shape that might be followed in order to design new shapes having better characteristics. The most promising possibility of improvement was found to be with those airfoils which have the position of the maximum camber well forward. A number of sections of this type have therefore been developed from the original family with the expectation of finding new sections that give a reasonably high maximum lift without an excessively large pitching-moment coefficient.

Among the 78 related airfoils considered in the published report are some having thickness forms differing from the basic one, notably those having leading

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edges blunter and sharper than the basic leading edge. The consideration that the airfoil profile must enclose an efficient structure, however, dictates the investigation of other thickness forms. With single-spar construction, for example, an airfoil section having the maximum thickness well forward may be desirable. On the other hand, for wings like the Fowler variable-area wing a deep rear spar may be required. A thickness form having the maximum thickness farther back than 0.3c may then be desirable. Furthermore, various thickness forms have never been studied under conditions corresponding to full-scale airplane wings. Some thickness forms, such as one having the maximum thickness at 0.4c, which appears from tests in the high-speed tunnel to be better than the basic one at very high speeds, may in flight be more efficient aerodynamically.

Scale effect.—The results of airfoil tests in the variable-density tunnel and in the full-scale tunnel as well as indications from flight tests show that a rather large variation of airfoil characteristics with the Reynolds Number is to be found within the range of values of the Reynolds Number encountered in flight. Data from tests of an airfoil at only one value of the Reynolds Number cannot therefore be considered adequate, but must be supplemented by some knowledge of the changes produced by varying the value of the Reynolds Number from that of the test.

The Reynolds Numbers common to modern flight lie in the range between 2,000,000 and 20,000,000. Airfoil results from wind-tunnel tests have been available only up to a Reynolds Number of about 3,000,000, obviously indicating that an extension of airfoil characteristics further into the flight range is highly important. The characteristics of the Clark Y airfoil were therefore measured in the full-scale tunnel over a range of Reynolds Number from 350,000 to 5,600,000 at maximum lift, and from about 350,000 to 9,000,000 at minimum drag. This wide range was obtained by testing four similar metal airfoils with spans of 12, 24, 36, and 48 feet at velocities from 30 to 118 miles per hour.

The maximum lift coefficient for the Clark Y airfoil shows a steady rise in value with increase in Reynolds Number while the minimum drag coefficient shows a decrease in value with increase in scale. A report is in preparation indicating the variation of the airfoil characteristics with Reynolds Number, and making available for design purposes these large-scale data.

Tapered airfoils.—Other work on airfoils includes routine tests or the tabulation and analysis of data requested by the military services, or by the Department of Commerce. Some of these investigations have dealt with tapered airfoils rather than airfoil sections. Several tapered airfoils were tested in the variable-density tunnel at the request of the Army Air Corps to provide data for inclusion in the handbook of instructions for airplane designers. In connection with the investigation of tapered airfoils a technical note (no. 483) has been prepared presenting in short form for convenient use by designers the theoretical pitching-moment characteristics of tapered wings having various plan forms and having sweepback and twist. The information is applicable to the design of wings for ordinary airplanes as well as tailless airplanes.

Compressibility effects.—A technical report has been published (no. 463) giving a description of the high-speed tunnel and an account of the tests of a series of six commonly used propeller sections, showing the effects of compressibility at air speeds up to 85 percent of the velocity of sound. The investigation of the effects of compressibility has been further extended during this year to include a study of the important variations of airfoil shape. Eleven related symmetrical airfoils have been tested over a wide speed range to determine the effects of variations in the leading-edge radius, the thickness, and the location of the maximum ordinate, as well as the effects of compressibility. The analysis of these results is now nearing completion and it is indicated that the best position for the maximum ordinate is 40 percent of the chord aft of the leading edge. The effects of variations in the leading edge radius on minimum profile drag for airfoils 9 percent thick are negligible for values of the radius less than 0.0089c.

The results of this investigation were used to determine a thickness distribution for use in the development of cambered airfoils. Three cambered airfoils were tested; one of these, the National Advisory Committee for Aeronautics 216 airfoil, is superior at high speeds to both the Clark Y and R.A.F. 6 propeller airfoils having the same thickness. This airfoil is 9 percent thick; its maximum ordinate is at 40 percent of the chord aft of the leading edge, and its leading-edge radius is 0.0022c (approximately one quarter the usual value for the National Advisory Committee for Aeronautics family airfoils). The mean camber line corresponds to that of the National Advisory Committee for Aeronautics 24 series.

A detailed investigation of the drag of fundamental shapes—circular, elliptical, and prismatic cylinders—is now in progress. The tests are being conducted over a speed range extending up to approximately 65 percent of sound velocity. Drag tests of cylinders of various sizes show remarkably close agreement when the results for the lower speeds are plotted against Reynolds Number and the results for all the circular cylinders are in excellent agreement as to the speed (0.4 sound velocity) at which the compressibility effects become of first importance.

Boundary-layer control.—A number of investigations have been made in previous years, both by the Committee and elsewhere, showing rather startling effects of the use of blowers to suck air in through slots in the surface of a wing or to blow it out. Most of these investigations have been made on relatively small models, and trustworthy results have been difficult of attainment because of the smallness of the models and because the amount of auxiliary apparatus required and the method used for attaching it to the model necessitated numerous corrections. An investigation is now in progress in the propeller-research tunnel in which a large model is used with the blower in the wing itself. In addition to the measurements of lift and drag, apparatus has been installed for measuring the thickness of the boundary layer and the pressure distribution over the wing. The power input to the motor is, of course, measured also. Although it is realized that the use of a blower for suction or pressure is not now attractive from a practical standpoint, it is believed the results will provide a definite contribution to our knowledge of the boundary-layer characteristics of the wing.

JET-BOUNDARY INVESTIGATION.—The unique possibility of obtaining results in the full-scale tunnel for direct comparison with flight results made it important to investigate all factors which might tend to cause a discrepancy between the wind-tunnel and flight results. That the limited boundary of a wind-tunnel jet causes a change in the aerodynamic characteristics of a body tested therein is well known, and at the time this tunnel was put in operation there was no theoretical correction factor available for this type of jet. An investigation was therefore undertaken to determine experimentally the jet-boundary correction factor. The results have verified in a very satisfactory manner the theoretical factor for this jet which became available during the progress of the work.

The procedure consisted in measuring the characteristics of geometrically similar airfoils graded in size from large to small and then in extrapolating plots of these measured characteristics to simulate the condition of a finite wing in space. A preliminary study of the test data indicated an apparent contradiction of the general theory of jet boundary. After further investigation this discrepancy was clarified when a distortion of the velocity field in front of the airfoil, caused principally by the wake from the body carried around through the return passage, was shown to be responsible. A close agreement was shown to exist between the characteristics of several airplanes as measured in flight and in the tunnel when the jet-boundary correction and the correction for wake effect or blocking were applied. The results of this investigation are being prepared for publication as a technical report. The theory for an airfoil of finite span in an open rectangular wind tunnel has been covered in Technical Report No. 461.

STRUCTURAL LOADING.—The studies of the flight loads on airplane structures which have been made in the past 3 years have resulted in a marked advance in knowledge of this subject. These investigations have been continued, either to add to the existing statistical data on some phases of the subject or to pursue further the underlying principles of phenomena not yet clearly understood.

Load factors.—Four airplanes have been used in an investigation of the relation between control forces and acceleration in pulling out of fast dives. A theoretical study of this relation has also been made to determine the possibility of utilizing a stick-force formula in load-factor estimates. The results of these investigations indicate (1) that the stick force has no appreciable influence on the probable applied load factor in those cases where the forces are within the pilot's strength, (2) that the pilot's opinion of the control "heaviness" and maneuverability of the airplane may be greatly influenced by a number of qualities of the airplane not directly related to the stick force, and (3) that stick-force formulas are untrustworthy for estimating probable applied load factors.

A statistical study of applied load factors and corresponding air speeds has been in progress on a number of airplanes under actual operating conditions, for which a special type of instrument has been developed. The instrument records acceleration and air speed, and has been named the "V-G recorder." A number of these instruments have been in constant use throughout the past year on various military and naval aircraft, commercial transport airplanes, and a few privately owned airplanes. The data being collected cover the loadings experienced in normal operation, ranging from the conditions corresponding to violent maneuvers to those resulting from atmospheric gusts. Although the data so far accumulated are insufficient to justify final conclusions, a very considerable advance has been made in knowledge of the loading conditions to which airplanes are subjected. Among several interesting points which have developed in regard to the loads resulting from gusty air, perhaps the most impressive was a load factor of 5.2 applied by a gust on an airplane cruising at 190 miles per hour. This value, while unusual, illustrates the possibility of large gust loads in rare instances. Assuming a sharp-edge gust, the gust velocity for this case was computed to be 40 feet per second.

Load distribution.—Several questions relating to the problem of load distribution have been given attention during the year. Since the preparation of Technical Report No. 445, which presents working charts for the determination of the lift distribution between biplane wings, further study of this subject has resulted in Technical Report No. 458. The influence of the fuselage has been evaluated from pressure-distribution tests made on two conventional biplanes in flight. This latter information may easily be used in conjunction with the charts for the pure cellule.

Studies have also been made of the influence of biplane interference on the moment coefficients of the individual wings and on the span-load distribution. In regard to the moment coefficients, it has been found that the biplane effect is completedly overshadowed by other influences such as surface roughness, imperfect profiles, and experimental error. The span-load distribution does not appear to be appreciably influenced by biplane interference.

Experimental pressure-distribution investigations have been continued on an observation airplane and a diving bomber. The results have not yet, however, been completely analyzed.

Field of View.—The field of view from an airplane cockpit or cabin is generally classified arbitrarily by the occupant as "good" or "poor." An investigation has been started to establish a suitable criterion by which to rate airplanes in this respect. An apparatus has been developed for measuring the extent of the view from any seat in an aircraft and several service-type airplanes have already been mapped. A report now in preparation will give data from a sufficient number of representative airplanes to make possible the development of a criterion for determining relative fields of view.

Rain-Vision Windshield.—An investigation has been completed in the 7- by 10-foot tunnel on a full-scale model of a cabin fuselage for the purpose of exploring the possibilities of obtaining satisfactory vision through open windows under conditions of rain and fog. The rain was simulated by a controlled spray located upstream from the fuselage. Tests were made with openings of various forms directly forward and to the side, which resulted in a side-window arrangement which is inclined inward to give straight forward vision and which can be completely opened without the entrance of even large drops of rain. A report is in preparation describing the tests and giving the proportions of the successful design.

Sources of Noise in Aircraft.—The fundamental research on the source and character of propeller noise has been continued. During the past year the work has been confined to a study of model propellers. The noise from such propellers has been analyzed and is found to consist in general of two groups of sounds. One group consists of a musical note whose frequency is connected with the speed of rotation, with its train of harmonics. The other group is composed of much higher frequencies, nonmusically related, which are undoubtedly generated by the shedding of vortices from the trailing edge of the blades. The effect of changes in tip speed and angle of attack upon these two types of sound has been investigated. The manner in which the ear responds to noises of this sort, together with several possible methods of estimating loudness, has been studied.

Vibration Research.—Tests with an airplane in floating suspension excited by a sinusoidal force were continued, the response of the fuselage and wings to the various frequencies being studied. In the particular airplane it was found that a large response occurred near the normal operating speed of the engine. In order to facilitate the observation of vibrations on all points of an airplane structure, a new instrument has been developed which permits instantaneous readings, obviating laborious preparations and precautions. A number of flight tests have been performed for the purpose of identifying vibrations of pure aerodynamic origin. Preliminary tests on a biplane disclosed considerable disturbances of irregular type in the range of 400 to 650 per minute. These disturbances could only be observed at diving speeds or above the stalling angle; no vibrations that could be attributed to aerodynamic forces were recorded in normal flight conditions.

Rotating-Wing Aircraft.—Because of the possibility of obtaining sustentation with little or no forward speed and the consequent possibility of safe flight at low speeds, continued attention has been given during the past year to three promising types of rotating-wing aircraft.

The first is the familiar autogiro in which the rotor axis is vertical, the rotation of the rotor occurs automatically as a result of air forces acting on the rotor blade, and lift on opposing blades is equalized by a flapping motion of the blades. Investigations have been made of the various elements controlling the performance of this type of machine, and one such investigation, which consisted of determining the rotor blade motions and the division of load between the rotor and the fixed wing, has been completed and described in Technical Report No. 475. The results of this investigation served two purposes: (1) The measured loads on the fixed wing have aided in the formulation of design rules for the fixed wings of this type of aircraft, and (2) the load on the rotor correlated with the measured blade motion has provided data needed for a theoretical study of rotor characteristics, the results of which are now being prepared for publication. A brief investigation of the vibrations occurring in a 3-blade autogiro has also been completed, and flight tests are in progress for the purpose of determining the effect of the incidence of the fixed wings on the rotor characteristics and on performance in general.

The second type of rotating wing being investigated, the gyroplane, is similar in general principle to the autogiro, but is fundamentally different in regard to its rotor operation, in that opposite blades of the rotor are rigidly connected and lift on these blades is equalized by oscillation about an axis parallel to the blade span. A theoretical analysis of this type of machine has been completed and is now in preparation for publication.

The third type being investigated, the cyclogiro, derives its lift and thrust from a power-driven rotor consisting of several blades rotating about an axis parallel to the lateral axis of the aircraft. A theoretical analysis of the cyclogiro has been completed and a simplified aerodynamic theory of the machine has been prepared and published (Technical Note No. 467). The analysis indicates that the aerodynamic principles are sound, that hovering flight, vertical climb, and a reasonable forward speed may be expected with a reasonable expenditure of power, and that autorotation in a gliding descent is available in the event of engine failure.

The studies on all three types of rotating-wing aircraft are being continued mainly in the form of wind-tunnel investigations principally for the purpose of improving the rotor characteristics of the autogiro and gyroplane and confirming the soundness of the principles involved in the cyclogiro.

AIRSHIPS.—Airship work has been confined to some miscellaneous activities such as cooperation with the Army in speed trials with the *TC-11* and *TC-13* airships, cooperation with the Navy in speed and deceleration tests with the U.S. airship *Macon*, and the emplification of previous reports to the Navy giving data obtained in the trial flights with the U.S. airship *Akron*.

SEAPLANES.—A description of the National Advisory Committee for Aeronautics tank, or seaplane channel, has been prepared and issued as Technical Report No. 470. Reference is made in the report to the important items of equipment and the satisfactory behavior of the rubber tires, the towing carriage, and the towing gear. The research program has followed quite closely the program outlined in last year's report. Although emphasis has been placed on investigations which have immediate application, the addition of wave suppressers has greatly expedited the carrying out of the research program.

Effects of variation in dimensions and form of hull on take-off of flying boats.—The effects of variation in dimensions are being studied by tests of a series of five models derived from a parent form by systematic variations in dimensions. The five models were investigated according to the general method in which the resistance, rise, and trimming moment of the model are determined at various fixed trims over a range of speeds. The results show that the performance of the parent model could be improved by changing its form to give a longer and flatter forebody. A new forebody was made and tested with the original afterbody, and the improved model equals in performance the best flying-boat hull. Tests of two models, nos. 11 and 11A, are described in Technical Notes Nos. 464 and 470.

Observation of the behavior of the models of hulls tested suggested the possibility of improving performance by a radical change in the form of the main step. A model was prepared in which the step was much deeper than usual and was pointed in plan form instead of square across the hull. This model, no. 22, showed a general performance much superior to the previous model. These results will be issued as a technical note and it is hoped that a full-scale test of this form may be made to determine its behavior under operating conditions.

A model of a flying-boat hull having one form of stub wings or sponsons to provide lateral stability was investigated. Other forms of sponsons have been made for tests with the same main hull, and in view of the later development of this type of lateral stabilization, it is planned to extend the application to hulls of other shapes.

Floats for seaplanes.—In order to obtain information regarding the performance of a good high-speed seaplane float, tests were made of a model of a float used on the Macchi racer of 1926. As a result of the tests a float designed to be an improvement of this float and to be used as a parent of future series was tested. This model showed a marked improvement over the Macchi float. The results of the two tests are compared in Technical Note No. 473.

Fundamental information regarding planing surfaces.—For a large part of the take-off run of the seaplane, that part of the weight of the craft not supported by the wings is supported by the hydrodynamic reaction of the water on the bottom of the float or boat. By testing surfaces that skim along the top of the water simulating only the bottom of a float, much valuable fundamental information can be obtained. A series of tests of planing surfaces consisting of flat surfaces at 0°, 10°, 20°, and 30° dihedral has been completed, and the results are being prepared for issue as a technical note. A series of somewhat similar models consisting of two surfaces with transverse curvature set at various dihedrals is being constructed for use in further tests. It is also planned to test surfaces with fore and aft curvature at a later date.

The results of the tests of these models may make possible the separation of the pure planing phenomena from the other factors encountered in tests of complete models and thus give valuable clues as to the proper form of bottoms.

Frictional resistance of boat surfaces.—Frictional resistance of those surfaces of a boat hull which are exposed to the passing water has not been determined for speeds from 30 to 60 miles per hour. The surfaces for a series of tests of frictional resistance, with their supporting gear, are completed, and the surfaces for another series nearly ready for investigation.

Specific tests for Government agencies.—A number of investigations specifically requested by the Bureau of Aeronautics have been conducted. An investigation of methods for the control of spray was made on a model of a Navy flying boat. It was found that the addition of spray strips gave some improvement, but in this particular case not as much as was desired.

At the request of the Army Air Corps, extensive tests were made of models of the hull of an amphibian flying boat to obtain information as to the water performance of the craft with various modifications.

BUREAU OF STANDARDS

WIND-TUNNEL INVESTIGATIONS.—The aerodynamic activities of the Bureau of Standards have been conducted in cooperation with the National Advisory Committee for Aeronautics.

Apparatus for measuring turbulence.—Because of the considerable weight and bulk of the present equipment for making turbulence measurements the possibilities of developing a light and easily portable type of instrument are being investigated. The problem is being attacked by two principal methods: first, by simplification of the present hot-wire type of apparatus by eliminating the batteries, and, second, by the direct measurement of forces on bodies such as spheres and cylinders.

Computation of boundary-layer flow.—A comparison has been made of the boundary-layer flow computed by the approximate method developed by Pohlhausen with the more exact solutions which have been published for several special cases. Approximate methods of the type suggested by Pohlhausen are useful in giving a picture of the flow in many cases, but their range of application is limited. A modification of Pohlhausen's method has been developed which extends the range of application and a comparison of the flow computed by this method with that of more exact solutions shows that the range of application has been increased at the expense of some decrease in the accuracy of the approximation. A paper describing the methods used in the computations has been prepared.

Cup anemometers.—An investigation of the effects of turbulence on the speed indications given by the ordinary hemispherical cup anemometer has been completed. When disturbances in the air stream were produced by a turbulence screen consisting of a wire net on which were loosely fastened small metal tags, the normal rate of the anemometer was found to be considerably increased. A systematic investigation has been made of the effects of roughening the outer surfaces of the cups.

AERONAUTIC INSTRUMENT INVESTIGATIONS.—The work on aeronautic instruments was conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department and included the investigations and the instrument development outlined below.

Temperature coefficient of elastic moduli.—The results of this investigation were published in the Bureau of Standards Journal of Research (R.P. 531) in March 1933.

Lubricants for instrument mechanisms.—The essential requirements of a lubricant for aircraft instruments include long life and operation at low temperatures. Mineral oils spread and therefore do not have a long life in the bearing. On the other hand, animal or vegetable oils do not spread but gum more or less slowly. An investigation was initiated to determine the characteristics of the oils available, including those with antioxidants, with a view to the preparation of specifications based on the performance of the best lubricant. Tests are being made on samples of about 40 oils. In addition to the customary tests given lubricants, each sample is being given two tests, the results of which it is hoped to correlate: (a) An accelerated oxidation test, and (b) a life test. The apparatus for the life test consists of a bank of 50 watch balance wheels, 3 or 4 of which are lubricated with the same oil, which are kept in oscillation by a suitable electromechanical device. The condition of the lubricant in each balance wheel is checked from time to time by measuring and comparing the time for the amplitude of the freely oscillating balance wheel to decrease from a given initial to final value.

Reports on aircraft instruments.—A report on aircraft power plant instruments, including descriptions of, and performance data on, tachometers, thermometers, pressure gauges, fuel-quantity gauges, and fuel-flow indicators was completed and will be published as Technical Report No. 466. Considerable progress has been made on two reports similar in scope on blind-flying instruments and on altitude instruments.

New instruments.—A number of new instruments were developed and constructed. These developments include the following:

A superheat meter of the resistance type has been completed and installed in the metal-clad airship *ZMC-2*. With this type a marked reduction in weight is obtained and a more rugged indicator can be used as compared with the thermocouple type.

An alarm which operates when the indication of carbon monoxide exceeds 0.02 percent has been developed and added to the M.S.A. carbon monoxide indicator.

An instrument was developed to indicate the level of the liquid air in the helium purifier apparatus. The level is indicated by the differential effect in the alternating currents from two external coils produced by a float in the liquid carrying a soft iron plunger.

An air-speed meter of the commutator-condenser type, the propeller and commutator unit of which are designed for mounting on an airplane strut, was completed.

A fundamental modification has been made in the venturi fuel flow-meter which in the usual form has been found to be unsatisfactory on airplanes. Air instead of gasoline is used as the medium by which the differential pressure developed by the venturi tube is transmitted to the indicator in the cockpit. The differential pressure developed by the venturi tube is transmitted to two flexible elements the differential action of which controls a valve regulating the suction within an air chamber. This suction is transmitted to the indicator. Several designs have been prepared and one instrument constructed which is ready for flight tests.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

COMPRESSION-IGNITION ENGINES.—The advantages claimed for the compression-ignition engine of reduced fuel consumption and the maintenance of power at altitude have been substantiated by recent flight tests of several compression-ignition aircraft engines. The power output per cubic inch of displacement of compression-ignition engines, however, is still inferior to that of conventional aircraft engines. The results obtained from an investigation of the performance of compression-ignition engines with boosting have shown that the increase in engine power with boosting is considerably less than that obtained with the carburetor engine. The research of the Committee has indicated that the method which holds the greatest promise for increasing the performance of the compression-ignition engine is to operate the engine on the two-stroke cycle. The investigation of the factors controlling the performance of a high-speed two-stroke-cycle single-cylinder compression-ignition engine has resulted in the attainment of a power output per unit of displacement which is 27 percent greater than that obtained with present commercial aircraft engines.

Fuel spray characteristics.—The attainment of efficient combustion in compression-ignition engines is dependent upon the distribution of the fuel sprays within the combustion chamber. Previous investigations of the Committee have shown that with fuel injected from round-hole orifices the greater part of the fuel is concentrated in the spray core. The effect on fuel-spray distribution of breaking up the core of fuel sprays has been investigated by injecting a small quantity of air at high pressure with the fuel oil. Spark photographs of the fuel sprays and measurements of the diameters of the oil drops in the spray showed that the use of the compressed air gave improved distribution and atomization of the fuel spray. An injection system incorporating this principle of fuel distribution was constructed and tested on a single-cylinder engine having a vertical-disk form of combustion chamber. The engine performance with the combined hydraulic and air injection system was not improved over that obtained with hydraulic injection except at high air-fuel ratios. The results obtained from the engine-performance tests indicated that with conventional hydraulic-injection pressures the atomization of the fuel was sufficient to result in good combustion. Additional methods of improving fuel distribution are to be investigated.

The penetration and distribution of fuel sprays following the cut-off of injection have been investigated with the National Advisory Committee for Aeronautics spray-photography apparatus. The object of the investigation was to obtain new knowledge concerning the distribution of fuel sprays for time intervals as great as 0.05 second after the cut-off of injection. The effects of air density, injection pressure, and air velocity counter to the fuel spray, on the spray distribution have been investigated. The results show that air-flow velocities from 15 to 25 feet per second directed counter to the fuel spray are very effective in distributing the fuel spray after injection cut-off, provided the fuel is well broken up during the injection process. The effect of these low air velocities on the spray core during injection is negligible.

Pintle-type fuel-injection nozzles have been used as a possible means of obtaining increased spray distribution. During the year spark photographs have been taken of fuel sprays from pintle nozzles. An analysis of the photographs shows that the angle of the spray from the pintle nozzle is approximately that of a spray from a round orifice and that the angle of the pintle has only a small effect on the spray angle. The penetration of the spray tip is comparable to that obtained with round-hole orifices. The results of this investigation are presented in Technical Note No. 465.

Injection-system characteristics.—A fuel-injection system has been developed to give a high rate of fuel discharge and to give discharge characteristics that do not vary with engine speed. The energy for injecting the fuel is supplied from a high-pressure reservoir at the pump in which the pressure is built up previous to the injection of fuel into the engine. The injection of the fuel is caused by the sudden opening of a pressure relief valve, which permits a hydraulic pressure wave to be transmitted through the injection tube to the injection valve. Injection of the fuel continues until the intensity of the pressure wave drops below the injection-valve closing pressure. With this injection system the period required for the injection of full-load fuel quantity for an engine having a bore of 5 inches and a stroke of 7 inches and operating at a speed of 1,500 revolutions per minute is only 10 crank degrees. This injection system is being used to determine the effect of the rate of fuel injection on the performance of compression-ignition engines.

An investigation has been made to determine the effect of placing a reservoir between the fuel-injection pump and the injection tube connecting the pump to the injection valve. The results show that the rates of fuel injection can be changed considerably by the use of such a reservoir and that the chattering of injection valve stems when a large discharge orifice is used can be prevented by using a reservoir of the correct volume.

Combustion in compression-ignition engines.—Although progress has been made toward decreasing the weight-power ratio of compression-ignition engines, the best ratio obtained is still excessive when compared with that of present-day spark-ignition aircraft engines. The decrease of this ratio is dependent upon an increase in the combustion efficiency of compression-ignition aircraft engines. The National Advisory Committee for Aeronautics spray-combustion apparatus has been used to determine the effect of the time for mixture formation on the course of combustion. The compression ratio used in the investigation was 12.7. In the preliminary tests the ignition of the fuel at a definite time in the cycle was insured by using an electric spark. The factors investigated were injection-advance angle, engine-coolant temperature, engine speed, and spark timing and location. Indicator cards were obtained with an optical engine indicator; continuous photographic records were taken of the movement of the combustion zone. These data showed the course of the combustion to be a function of the temperature and pressure to which the fuel had been subjected previous to the ignition of the air-fuel mixture. At low air temperatures it was found that the rates of combustion varied with the volatility of the fuel, but at high air temperatures this relationship did not exist and the rates depended to a greater extent on the chemical nature of the fuel. The results of this investigation are being prepared for publication as a technical report.

The rapid rate of pressure rise and high maximum cylinder pressures obtained in compression-ignition engines are detrimental to smooth engine operation. The rate of pressure rise and maximum cylinder pressure are influenced by the time required for the fuel after injection to absorb heat from the compressed air in the cylinder. Preliminary investigations conducted with a cam-operated fuel-injection pump and a diaphragm-loaded fuel-injection valve showed that preheating the fuel to 330° F. before injection reduced the ignition lag and the maximum cylinder pressure. For higher fuel temperatures the injection of the fuel became erratic. A conventional injection system has been modified so that it functions independently of the temperature of the fuel. Bench tests conducted with the injection system showed satisfactory operating characteristics for fuel temperatures of 900° F. The engine performance obtained with this injection system is being determined with the system installed in a compression-ignition engine having a high-velocity air flow for distributing the fuel spray.

Information relating to the composition of the fuel used, the air-fuel ratio, carbon monoxide content, and fuel wasted because of incomplete combustion may be readily obtained from an analysis of the exhaust gas from internal-combustion engines. Research has been conducted from five different engines to determine the relationship between hydrogen, methane, and carbon monoxide in the exhaust of four-stroke cycle engines using a large number of hydrocarbon fuels. It was determined that a linear relation existed between the carbon monoxide and the hydrogen found in the exhaust gas from engines using hydrocarbon fuels. A small amount of methane was found to be always present in the exhaust gas, but the amount was independent of the air-fuel ratio and of the hydrogen-carbon ratio of the fuel. These determined relationships and the use of the Ostwald combustion diagram make available all the information of a complete exhaust-gas analysis when any two factors (carbon monoxide content, carbon dioxide content, air-fuel ratio) are known. The investigation has been reported in Technical Report No. 476.

Hydrogen as an auxiliary fuel for compression-ignition engines.—The designers of airships are of the opinion that the successful commercial airship must be powered with compression-ignition engines. The use of compression-ignition engines reduces the fire hazard and makes it possible to operate over a wide range of engine speeds with low specific fuel consumptions. Additional lift and a reduction in weight of the water-recovery apparatus used with helium would be obtained in commercial airships by the use of hydrogen stored within the helium cells. Since the hydrogen required to lift a given weight of fuel contains a quantity of heat energy equal to 20 percent of the heat energy of the fuel, it would be desirable to utilize this energy in driving the airship by burning the hydrogen in the engines.

The Committee has conducted a research to determine the quantity of hydrogen that can be mixed with the inlet air and burned in a compression-ignition engine. A single-cylinder compression-ignition engine operating at a speed of 1,500 revolutions per minute was used in this investigation. The engine was operated at compression ratios of 13.4 and 15.6. The results indicated that a sufficient quantity of hydrogen could be burned with all useful fuel-oil quantities to compensate for the increase in lift due to the consumption of the fuel oil. Quantities of hydrogen from 5 to 14 percent of the inducted air by volume could be burned, depending upon the engine conditions. More power could be obtained from the engine when the composite fuel was used. At light loads the thermal efficiency was less than that obtained with fuel oil alone, but at full load the efficiency was greater with the composite fuel. The engine could be stopped by shutting off the supply of liquid fuel, since it was found impossible to ignite the hydrogen-air mixture by compression. A report of this investigation is being prepared for publication.

Combustion-chamber investigation—Integral type with no effective air flow.—The results of the investigation made to determine the effects of scavenging the clearance volume and boosting on the performance of a compression-ignition engine with an integral combustion chamber having no effective air flow have been published as Technical Report No. 469. This research, conducted at a compression ratio of 12.6, has been extended to include the determination of the engine performance obtained at compression ratios of 10.5 and 15.0. The engine-operating characteristics were found to be quite different at these compression ratios. At a compression ratio of 10.5 starting is difficult and the ignition lag under standard test conditions is more than one third longer than that obtained at a compression ratio of 15.0. The rate of pressure rise at the lower compression ratio as determined from indicator cards is nearly double the corresponding values obtained at a compression ratio of 15.0. Starting was easier at the higher compression ratio and operation smoother, with more uniform explosion pressures.

Combustion-chamber investigation—Prechamber type with high-velocity air flow.—Progressive changes made to the shape of the prechamber and of the connecting passage have resulted in an 18 percent increase in the brake horsepower developed by a single-cylinder compression-ignition engine when operating with the theoretical full-load fuel quantity and with an engine speed of 1,500 revolutions per minute. The results of previous investigations indicated that improvement in performance was the result of intensification of the air flow, and the first change in shape was the use of a passage tangential to the spherical chamber instead of the radial passage that had been used for the purpose of symmetry in previous investigations. The tangential passage caused a forced rotation of the sphere of air in the chamber which persisted during injection and combustion of the fuel and improved the engine performance. The tangential passage was tested as a straight passage and also as a tapered flared passage. Best results were obtained with a passage slightly flared at the cylinder and tapered toward the prechamber.

As a further means of intensifying the air flow, the auxiliary chamber shape was changed from a sphere to a disk with rounded edges to eliminate the comparatively low-velocity air at the poles of the rotating sphere. This change in shape was effective in increasing the engine power. Changes in the direction of the connecting passage in an attempt to produce an air swirl in the cylinder seemed to have no beneficial effect. The use of three passages diverging from the cylinder, however, resulted in smoother engine operation, although the performance was slightly inferior to that obtained with the single passage. An increase in the fuel-spray penetration obtained by increasing the length-diameter ratio of the injection-valve orifice from 2.5 to 6.0 resulted in a slight increase in power output.

Two-stroke cycle investigation.—The use of the compression-ignition engine as a power plant for airplanes is dependent upon obtaining a power output per cubic inch of displacement comparable to that obtained with the conventional spark-ignition aircraft engine. A method of increasing the power output of compression-ignition engines is to operate engines of this type on the two-stroke cycle. The factors affecting the performance of a two-stroke-cycle compression-ignition engine are being investigated with a single-cylinder water-cooled engine having a 4.625-inch bore and a 7-inch stroke, and operating at a maximum speed of 1,800 revolutions per minute. The factors investigated include the distribution of the fuel spray, the scavenging air pressure, the engine speed, and the injection timing. The variation in fuel-spray distribution was obtained by varying the size, number, and arrangement of the fuel-valve orifices and the number and position of the fuel-injection valves.

Based on the results of these tests a single injection valve having a three-orifice nozzle was selected for continuing the tests. With increase in the scavenging air pressure the brake mean effective pressure increased linearly to 152 pounds per square inch at a pressure of 3 pounds per square inch and a speed of 1,250 revolutions per minute. Performance tests at variable speed emphasized the importance of obtaining proper scavenging and charging of the engine cylinder. A description of the two-stroke-cycle test engine and the results of the preliminary engine tests are being prepared for publication.

Fire Hazard in Aircraft—*Hydrogenated safety fuels.*—The investigation of the engine performance obtained with a hydrogenated safety fuel injected into the engine cylinder has been continued, a fuel having a flash point of 125° F. and an octane number of 95 being used. The performance of a single-cylinder liquid-cooled engine has been determined with the hydrogenated safety fuel for compression ratios of 5.85 and 7.0, valve timings giving 30° and 130° overlap, inlet pressures from atmospheric to 5 pounds per square inch boost pressure, and engine speeds from 1,250 to 2,200 revolutions per minute. The best results were obtained by locating the single injection valve between the two exhaust valves so as to direct the fuel spray horizontally across the combustion chamber against the incoming air. The duration of fuel injection was from 60 to 70 crankshaft degrees and the start of injection from 70° to 90° after top center on the suction stroke. At a compression ratio of 7.0, a valve overlap of 130 crank degrees, a speed of 1,750 revolutions per minute, and a boost pressure of 1 pound per square inch, the brake mean effective pressure obtained was 175 pounds per square inch and the corresponding fuel consumption 0.50 pound per brake horsepower per hour. In general, for similar conditions the power obtained with the safety fuel was equal to that obtained with gasoline, although the fuel consumption with the safety fuel was 5 percent greater. The investigation has been described in Technical Report No. 471.

Increase in Engine Power—*Increase in engine speed.*—The two principal methods of increasing the power output of conventional aircraft engines are to increase the brake mean effectvie pressure and to increase the engine rotative speed. The performance obtained with the Committee's single-cylinder test engines has been limited to maximum speeds of 2,200 revolutions per minute. In order to extend the investigation on boosting to higher boost pressures and higher engine speeds, a single-cylinder liquid-cooled test engine has been designed and constructed to operate at a maximum speed of 3,000 revolutions per minute and a maximum explosion pressure of 1,500 pounds per square inch. A system of gear-driven counterweights is used to balance the engine. The test engine has been assembled and motoring tests of the engine are in progress.

Cowling and Cooling of Aircraft Engines—*Cooling properties of finned surfaces.*—The demand for engines of higher power and the general use of the National Advisory Committee for Aeronautics cowling or of ring cowlings on airplanes has necessitated a study of all possible methods for improving the cooling of air-cooled engines. An investigation to determine the effect of fin pitch, fin width, and average fin thickness on the temperature distribution in and the heat dissipation from steel cylinders having tapered fins has been completed. The range of fin pitches investigated was from 0.1 to 0.6 inch, the range of fin widths from 0.37 to 1.47 inches, and the range of average fin thickness from 0.04 to 0.27 inch. The cylinder diameter was maintained constant at 4.5 inches. The range of air speeds investigated was from 30 to 150 miles per hour. The experimental data obtained have been used as the basis for the development of a method for determining fin dimensions permitting the use of a minimum of material for a range of conditions of heat transfer, air flow, and fin materials. The results of the investigation will be made available in technical reports now in preparation.

Research has been conducted with several finned specimens enclosed by a shroud. A blower was used for supplying the cooling air and a Durley orifice box for measuring the air quantity. In these tests the effects on the heat transfer from the finned cylinder to the cooling air of a range of air densities from 0.0476 to 0.072 pound per cubic foot, cooling air temperatures from 113° F. to 192° F., and air speeds from 10 to 150 miles per hour have been investigated. For the cylinders tested the cooling was found to be proportional to the mass flow of the air raised to the 0.45 power.

The use of deflectors for directing the cooling air to the rear of the cylinder, thus increasing the amount of finned surface in contact with the cooling air, has been investigated with an electrically heated finned specimen mounted in a wind tunnel. In these tests it was found that the cylinder temperatures in the rear could be reduced 25 percent by the use of a sheet-metal deflector in contact with the fin tips. The best results were obtained with this deflector when the front edge of the deflector was from 70° to 90° from the front of the cylinder and the rear opening was large enough not to restrict the air flow. A duct about 3 inches long connected to the rear of the deflector appreciably improved the cooling. Welding the deflector to the fins increased the finned surface that dissipated heat to the air stream and appreciably reduced the cylinder temperatures. This investigation is to be extended to include tests of the more promising deflector and cylinder combinations at a range of air speeds from 50 to 200 miles per hour.

The design of the National Advisory Committee for Aeronautics cowling could be placed on a more rational basis if the minimum quantity of air required to cool satisfactorily a given design of engine cylinder and the pressure differences available for forcing the air through the cowling in flight were known. The minimum quantity of air required to cool satisfactorily a conventional design of engine cylinder is being determined with a single-cylinder test engine. The cylinder is shrouded and the cooling air supplied by a blower. The quantity of cooling air and the pressure drop through the cowling are being measured for a wide range of engine-operating conditions. The effect of varying the shape of the entrance and exit openings in the cowling on the quantity of air and pressure drop through the cowling are being investigated by the aerodynamics division by means of models of the cowling mounted in a wind tunnel.

Two-row radial engine.—At the request of the Bureau of Aeronautics, Navy Department, the Committee has determined the effect of air speed, engine power, and engine speed on the temperature distribution obtained with a two-row radial engine installed in a service airplane. The airplane was tested in flight and in the full-scale wind tunnel. The temperature distribution over the engine was investigated by means of 47 small-diameter wire thermocouples and two recording pyrometers. Thirty of these thermocouples were used to determine the temperature distribution over two representative cylinders, one in the front row and one in the rear. The effect on the cooling of the attitude of the airplane and of the number of propeller blades was also investigated.

INSTRUMENTS—*Hub dynamometer.*—The National Advisory Committee for Aeronautics hub dynamometer has been designed to measure and photographically record the torque developed by an aircraft engine in flight. During the past year work has been directed toward improving the torque-cell diaphragms. The original diaphragms machined from bar stock have been replaced by diaphragms machined from die forgings. Flight tests made with the dynamometer for a range of altitudes from sea level to 15,000 feet gave very encouraging results. The engine power as determined in flight was in good agreement with the calculated engine power obtained by correcting the sea-level brake horsepower for the pressures and temperatures at altitude. The temperature of the liquid in the torque cells was found to be the same as the free-air temperature and this fact will simplify the correction for temperature at high altitudes.

Engine indicators.—The increasing demand for pressure records from spark-ignition and compression-ignition engines requires that the precision and reliability of the pressure-recording apparatus be increased. Modifications of the Farnboro engine indicator used by the laboratory have been continued and the pressure element will now operate continuously under desirable engine-operating conditions. The length of service of the disk has been increased by eliminating the arcing at the disk and seats. The low-pressure portion of the engine cycle is being studied with the aid of a stroboscopic valve, designed primarily for obtaining gas samples from an engine cylinder.

A new optical indicator which records photographically the variation in pressure with time has been developed for use with the National Advisory Committee for Aeronautics spray combustion apparatus. The large windows in the combustion apparatus permit the use of a diaphragm having a diameter of 2 inches. The measured frequency of the diaphragm, mirror, and mirror staff is approximately 9,000 vibrations per second.

BUREAU OF STANDARDS

Altitude tests of aircraft engines.—Altitude tests of a Curtiss D-12 engine, in which the jacket water outlet temperature was varied over a range of nearly 70° C., showed that friction decreases and fuel economy improves at all altitudes as the temperature of the jacket water is increased. At sea level and low altitudes the power output decreases with increasing jacket-water temperature, but at high altitudes the brake horsepower increases on account of the predominant effect of the decrease in friction. A report of these tests will be published as a technical note.

Pistons giving compression ratios of about 6, 7, and 8 were obtained from the Army Air Corps for use in studying the effect of compression ratio upon the variation of horsepower with exhaust pressure, and the runs at one compression ratio have been completed.

Phenomena of combustion.—A detailed study was made of the effect of water vapor on the speed of flame in space in equivalent mixtures of carbon monoxide and oxygen at low pressures. Among numerous results of this investigation it was found in particular that, for low-pressure explosions of these gases, a moderate increase in the amount of water vapor was sufficient to double the flame speed, and that the greater the pressure of the active constituents the greater was the accelerating action. These facts indicate that the control of the water-vapor content in mixtures of carbon monoxide and oxygen is very important in any investigation involving measurement of flame speed. Provisions were made for adequate control of this factor in new apparatus which has been built for continuing the study of gaseous explosive reactions.

Combustion in an engine cylinder.—Measurements have been made of the variations during combustion in the intensity and spectral distribution of the radiant energy (to 11μ) emitted by the flame at two widely separated points in the engine combustion chamber and under a variety of operating conditions. The series of filters used in obtaining spectral distributions for the engine flames was used also in making supplementary observations of the radiation from a black-body furnace at different temperatures and from burner flames of diverse fuels.

Preliminary analysis of these data indicates that the great bulk of the energy radiated by the engine flame is in the infrared and exhibits strongly under all conditions the characteristic emissions of water vapor and carbon dioxide, while radiant energy from incandescent carbon is relatively weak and insufficient to serve as a basis for estimating flame temperature. Although total radiation varies greatly during an engine cycle and considerably for different operating conditions, spectral distribution shows little change over a wide range of conditions. In a normal explosion, radiation begins to increase upon arrival of visible flame under a window and continues to rise for 20° or more of crank movement thereafter, which indicates that reactions producing highly active molecules of water vapor and carbon dioxide continue to a considerably greater depth behind the flame front and for a longer period in a given unit of charge than is generally supposed. In a knocking explosion, these reactions apparently are completed much more rapidly after inflammation in that part of the combustion chamber which is remote from the spark plug.

Pressures and temperatures in aircraft engines.—A pressure element of the balanced-diaphragm type has been constructed for use on the C.F.R. research engine. The design incorporates certain experimental features which may prove useful in attaining the high degree of simplicity and compactness necessary to the construction of a reliable combination spark plug and pressure element for aircraft-engine use. Maximum diaphragm diameter and provision for adjusting the zero reading while the indicator is on the engine also were incorporated in the present element to give high accuracy in studying low-pressure phenomena, while the passages between the diaphragm and the engine combustion chamber were made very short to prevent distortion of the peaks of the indicator diagrams.

Ignition research.—The ignition laboratory has been engaged in various confidential investigations for the Bureau of Aeronautics, Navy Department. Further work has been done on the problem of measuring the electrical characteristics of the spark discharge and a paper on the character of spark discharges is being prepared for publication in the Bureau of Standards Journal of Research. An improved type of low-capacitance ignition cable has been developed which overcomes one of the main objections to shielding from the ignition standpoint. Apparatus has been devised for comparing the effectiveness of different types of shielding as regards radio reception. The study of hydrocarbon oxidation has been continued and a method has been perfected for obtaining photographic records of the changes in absorption which occur during a single engine cycle when a beam of light is passed through the combustion chamber of an engine.

Detonation rating of aviation gasolines.—The C.F.R. Motor Method, which is in general use for the knock rating of motor fuels, has been recommended for use in rating commercial aviation gasolines pending the adoption of a C.F.R. Aviation Method. A program of multicylinder engine tests to ascertain how much tetraethyl lead or benzol in certain typical base fuels is required to match the detonation characteristics of three reference fuels (rated, respectively, 73, 80, and 87 octane number by the C.F.R. Motor Method) has been adopted and the tests will be made by the Bureau of Standards in cooperation with four engine manufacturers. Each of the five laboratories will use representative commercial or military aircraft engines and the average performance of the diverse test fuels will give a basis for developing a suitable laboratory method of rating aviation gasolines.

Ice formation in the induction systems of aircraft engines.—A study of the relation of fuel volatility to ice formation in the induction systems of aircraft engines was undertaken in December and is nearly completed. The fuels used included three conventional aviation gasolines, selected to cover the commercial volatility range, and three aviation natural gasolines, differing widely in volatility. Small-scale tests at sea level and at altitude, using a thermally insulated carburetor through which conditioned air was drawn by means of a Nash pump, showed that it was possible to predict quite accurately the atmospheric conditions under which a fuel would cause ice formation in the carburetor from a knowledge of the distillation curve of the fuel and the supplied air-fuel ratio. Full-scale tests with a Curtiss D-12 engine mounted in the altitude chamber verified the results obtained in the small-scale tests, ice being formed at the same venturi temperatures in each case within a few degrees.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT

SUBCOMMITTEE ON METALS

Intercrystalline embrittlement of sheet duralumin.—A report entitled "The Weathering of Sheet Aluminum Alloys Used in Aircraft", which summarizes the results of exposure tests of 5 years' duration has been prepared for publication as a technical report. The tests in which were obtained the data upon which the report is based were conducted upon both commercial alloys and special compositions by exposing them continuously to the weather at three locations: Washington, D.C.; Hampton Roads, Va.; and Coco Solo, Canal Zone. The resulting changes in the tensile properties as determined at intervals of several months during the duration of the tests have been used as the principal measure of the corrosive effect by comparison with the corresponding properties of similar materials carefully stored under noncorrosive conditions. The change in the product of tensile strength and elongation expressed as a percentage of the original was found to be very useful for this purpose. All specimens after corrosion were examined as to the character of any corrosive attack which had occurred and its relation to the microstructure.

In addition to showing the useful life which may be expected of the various materials under different climatic conditions, the investigation has clearly established a number of important facts relating to (a) the underlying causes of intercrystalline embrittlement of duralumin, (b) the most desirable method of heat treatment for developing reliable material having the high strength required, and (c) the dependability and usefulness of various protective coatings and surface treatments.

Numerous advances have been made in the development of light alloys since the exposure tests referred to above were started. Early in the year a second series of tests intended to cover a 5-year period was started. The general plan is similar to that of the tests just completed, with a few improvements, however, prompted by the first series. Considerable progress has already been made in the testing of the specimens removed at 3-month and 6-month intervals from the racks. The materials included in the tests represent 19 aluminum-base alloys and 9 magnesium-base alloys. Fifteen hundred specimens have been used at each test location. Fourteen methods for surface treatment and 12 different types of coatings are represented. Close cooperation has been given by the manufacturers of the materials as well as of the various coating materials which form a part of the test.

Exposure tests of magnesium and magnesium alloys.—Observations on materials in sheet form and as thin castings exposed continuously to the weather have been continued. The average change in tensile strength of the sheet material after 4½ years' exposure to the weather at Washington was of the order of 15 percent. Most of the surface coatings failed within 1½ years. Outstanding exceptions were aluminum-pigment spar varnish and an "acid-seal" coating on a red-lead primer. With the completion of the 5-year period, all of the specimens will have been tested and a report will be prepared. As part of the new series of exposure tests mentioned above, various magnesium alloys have been included. These will furnish information on the dependability of the materials under seacoast conditions.

Protection of duralumin, anodic oxidation.—The practical value of treating the surface of duralumin parts by an anodic oxidation process is now generally recognized and specified in airplane construction. Study of the various electrolytic methods used for this purpose has been continued and has resulted in improving and simplifying the method considerably. A number of modifications of the usual chromic-acid solution have been developed and progress has been made in the explanation of the deterioration of the electrolytic bath during use, whereby the surface oxide film formed in treatment of successive lots is less and less effective. Close contact with the Naval Aircraft Factory has been maintained.

Airplane propellers—Aluminum alloy.—The continued sporadic failure of propeller blades constitutes a serious problem to aircraft. During the year 8 aluminum alloy blades, 4 with hub failures and 4 with blade failures, were studied. All were fatigue fractures. Those at the hub originated at the periphery approximately in line with the trailing edge. The metallurgical examination did not reveal any significant defects in material nor heat treatment. Stresses associated with the method of clamping the blades in the steel hub appear to have more bearing on the hub failures than defective material.

Failures in the blade itself, beyond the hub, originated on the flat side of the blade, the fractures being suggestive of a coarsely crystalline brittle metal. Ordinarily fatigue fractures in aluminum alloys have a comparatively smooth surface. Preliminary experiments have indicated that fatigue cracks formed in the aluminum alloy blades by a few thousand cycles of reversed stresses greatly in excess of the fatigue limit were similar in appearance to those formed in the blades that failed in service.

In the examinations of the metals of the failed blades two rather unusual types of metallographic markings within the structure of individual grains were discovered, one being a veined structure and the other crisscross or "slip-line" markings. The cause and significance of these markings have not yet been determined. Both have been eliminated by suitable heat treatment and neither appears to have a marked effect upon the tensile properties of the material.

Airplane propellers—Steel.—Examination of the fracture of a failed welded steel propeller revealed a fatigue fracture, associated with a defect in the weld on the leading edge. Other portions of the welds in this blade and some other similar blades showed defects of various sorts. A study was made of nondestructive methods applicable to the inspection of such blades. The use of a magnetic powder dusted on the magnetized blades was considered to be most practicable. It was found that this method revealed some defects which were not shown by an X-ray examination.

A thorough study was made of hollow welded steel blades furnished by the manufacturer and a detailed report prepared describing the necessary technique to be employed and illustrating the patterns formed by the various defects. This report was intended for the use of inspectors in routine inspection in the field and in the manufacturer's plant. The information was supplied to the Aeronautics Branch of the Department of Commerce, the Army Air Corps, and the Bureau of Aeronautics of the Navy.

SUBCOMMITTEE ON AIRCRAFT STRUCTURES

Inelastic behavior of duralumin and alloy steels in tension and compression.—A procedure has been developed for the determination of the stress-strain properties in compression of sheet and thin-walled structures. In this test a number of coupons are cut from the material and placed together like leaves in a book. Buckling of the outer leaves is prevented by a number of steel studs inserted between the specimen and an auxiliary frame. The preliminary tests indicate that values for a yield point can be obtained which can be repeated by different observers and, in the case of coupons cut from tubing, compared with values obtained in the test of tubes with a length-radius ratio of about 15.

End fixation of struts.—The laboratory work on round normalized or annealed chromium molybdenum steel, duralumin, and high-strength stainless-steel tubing has been completed. Formulas similar to those by Orrin E. Ross published in Technical Note No. 306 of the National Advisory Committee for Aeronautics have been developed, which represent with a good degree of accuracy the relation between the column strengths and the geometric properties of Navy standard steel tubes and S.A.E. standard duralumin tubes passing Navy Department specifications for the tubing tested. From these formulas curves have been drawn giving the axial load which can be carried by any standard tube of any free length up to 200 times the slenderness ratio or 200 inches, whichever is the smaller.

Friedrich Bleich's method of designing compression members with elastically restrained ends has been extended so that it is now possible in trusses to design such members against buckling in the plane of the truss with considerably greater accuracy than before. The method consists essentially, after making a preliminary design, in assuming as freely supported the far ends of all members meeting at either end of a member to be designed finally, and then determining the free length of the latter. A nomographic chart has been worked out which materially assists in this determination. When the free length has been found, the rest is merely a matter of selecting the proper section, either by the use of the appropriate column formula, or from the corresponding load-free-length curves.

Torsional strength of tubing.—The report on the torsional strength of chromium molybdenum steel tubing, which has been prepared in manuscript form, is being held in abeyance awaiting the results of the parallel program on 17ST duralumin tubes.

The experimental part of this latter program has been completed. Tubes of the following sizes are included: 1-inch diameter, 0.018 to 0.120 inch thick; 1-inch diameter, 0.022 to 0.220 inch thick; and 2-inch diameter, 0.022 to 0.220 inch thick. Torsion tests were made on tubes 20 inches and 60 inches long of each size; tensile and hardness tests were also made on tubes of each size.

It is planned to present the results of these tests as soon as they have been analyzed as the second part of a report on torsional strength of tubing, thus including in one report tubing of the two materials principally used in aircraft design.

Strength of riveted joints in aluminum alloy.—The majority of the testing fixtures and the heat-treating equipment have been constructed for this investigation. Tests have been made to determine the effect of hole and plate clearances in double-shear tests of the rivet stock. Tests have been started to determine the optimum driving pressure for a given rivet size, plate thickness, and grip, but these have not yet progressed far enough for definite conclusions to be given.

Vibration tests of propellers.—This investigation was undertaken in cooperation with other agencies of the Government in an attempt to gain a clearer understanding of propeller failures in flight. Most propeller failures are found to proceed from typical fatigue cracks which in turn must be due to high periodic stresses. The source and nature of these stresses are not known. It is not clear whether they are due to resonance vibrations of large amplitude superimposed on the steady stress due to the centrifugal forces or whether they are due to purely forced vibrations.

No answer to these questions can be expected until it has been shown whether or not either resonance vibrations or forced vibrations of sufficient amplitude can be maintained in a propeller to cause failure. It was therefore decided to begin the investigation by developing a method of exciting vibrations of controllable frequency and amplitude in the propeller, of measuring the stresses set up during this vibration, and, if possible, of producing fatigue failures.

Of the various methods considered the following was successful in accomplishing its purpose. A direct-current motor has its armature connected across an alternating-current source of variable frequency while its field is excited by a steady direct current; the rotor of the motor then performs torsional vibrations of the frequency of the armature current and an amplitude that may be controlled by controlling the field current or the impressed alternating voltage. This torsional vibration is transmitted through the shaft of the rotor to the propeller blades, which are mounted in a hub at the end of this shaft in the same way as an airplane propeller is connected to the crankshaft of its driving engine. The propeller executes a forced vibration, which becomes large whenever the impressed frequency coincides with one of its natural frequencies.

In the new equipment, which was installed after preliminary tests had shown the method to be practical, the impressed frequency may be varied from 10 to 180 cycles per second. As the frequency was increased gradually from its lowest value the first resonance vibration was observed between 30 and 40 cycles; the propeller blade vibrated approximately as a cantilever beam fixed at the hub end; a careful determination of the stress distribution in this mode was made, using 2-inch Tuckerman optical strain gages having a special heavy knife edge to reduce inertia effects. The stresses were found to vary linearly with the deflection of the tip of the blade. This result was utilized in making fatigue tests on eight propeller blades. The blades were run at a given tip amplitude, corresponding to a maximum stress amplitude given from the strain-gage measurements, until failure occurred. This failure took place in each of the eight blades by the formation of a crack at a point close to the observed stress maximum, which was 20 to 30 inches from the center of the hub of the propeller. The results were plotted on a diagram of logarithmic stress versus number of cycles to failure. However, the number of points was not sufficient to draw definite conclusions. The torque amplitude causing failure was of the order of 100 ft.-lb.

As the frequency was increased beyond the point corresponding to the fundamental described above, a torsional resonance vibration of the whole propeller about the driving shaft was passed at around 50 cycles, and finally at around 110 to 130 cycles a further bending vibration of the individual blades was reached, this time with a node about 9 inches from the tip.

The stress distribution for the mode was obtained for one blade and showed a maximum a few inches from the node.

The experimental investigation has been paralleled by a theoretical analysis. The stress distribution in a propeller of given design vibrating with its fundamental frequency was calculated by a method of successive iteration first applied to propellers by Hansen and Mesmer (Z.F.M., vol. 23, 1933). This gave a close check with the observed frequency and with the stress distribution obtained by the Tuckerman gages. The same method has been modified to compute the natural mode, frequency, and stress distribution due to the first harmonic with node near the tip.

The Matériel Division of the Army Air Corps has conducted a study of the resonant-vibration frequencies of propeller blades, using entirely different methods and equipment. The results of this investigation have been published (Air Corps Technical Report No. 3891), and show in general that the failures of propellers were due to the coinciding of the resonant-vibration frequencies of the propeller blades with the engine-explosion frequencies.

Airship girders and airship structural members.—A number of column tests have been made on two experimental and two production plate airship girders of aluminum alloy fabricated by the Goodyear-Zeppelin Corporation. These tests were made in the large Emery testing machine. The specimens were placed in the machine to simulate as nearly as practicable flat end columns. The lowest maximum load recorded for any of the specimens taken from the production girders was 27,450 pounds for a column 103.4 inches long. The determinations of the areas of the chord members are in progress.

Specimens of the original German duralumin lattices and channels from the airship *Los Angeles* have been submitted at intervals throughout the year. The results of the tensile tests on lattice and channel material do not suggest that there has been any appreciable progress in corrosion during the last year. In no piece tested was the corrosion sufficient to lower the strength of the ship.

A number of specimens of thin sheet Alclad cut from the hull plating of the airship *MC-2* have been tested in tension. The results of these tests do not suggest an appreciable deterioration as a result of corrosion. No hull specimen showed ultimate strengths of less than 54,900 pounds per square inch or elongations less than 15 percent.

The investigation of the stresses in wire loops has been continued. Studies have been made of the fractures of bulkhead fork wires. These fractures are attributed to fatigue. A satisfactory procedure for determining the residual stresses in wire helixes has been obtained. The determination of these stresses is proceeding as opportunity affords.

Flat plates under normal pressure.—The analysis of results from a detailed test of a 5 by 5 by 0.02 inch duralumin plate with clamped edges led to the following tentative conclusions:

The only known theory which gives a roughly adequate picture of the behavior of a plate of this type is that of Foeppl. The distribution of median plane stresses is roughly the same as that given by Foeppl; that of the bending stresses is very different. The magnitude of the maximum total stress which occurs at the middle of the edge of the plate is 10 to 20 percent higher than that predicted by Foeppl.

By the application of Foeppl's theory it can be shown that all curves of pressure versus center deflection obtained from tests of square plates of a given material with fixed edges can be reduced to one curve if the pressures are divided by the fourth power of the ratio of the thickness of the plate to its width, and the center deflection by the thickness alone. This curve was computed for square duralumin plates with logarithmic paper and it was found that all the observed curves when reduced come fairly close to this curve throughout the elastic range.

A number of stainless-steel plates have been tested under normal pressure; they showed the same behavior qualitatively as the duralumin plates reported on above.

Following a lead from an article in Z.V.I., vol. 26, 1932, a varnish was developed which cracked under a tensile strain from 1.3 to 2.3 10^{-3} in./in. corresponding to stress well below the yield point for duralumin. Rectangular duralumin plates were coated with this varnish and the formation of the definite strain pattern that developed as each plate was subjected to increasing normal pressure was followed; this strain pattern showed directly the extent to which the clamping at the short ends affected the stress distribution and it also showed the curve near the edges along which the surface strains reversed from compression to tension.

Strength of welded joints in tubular members for aircraft.—Tests have been completed on the majority of specimens of the second series of this investigation. A series of 216 butt-welded tensile specimens in chromium molybdenum plate 0.0325 inch to 0.1875 inch thick has been tested to determine the strengths obtainable in joints heat-treated after welding for three types of welding: The standard procedure using low-carbon rod; welding with chromium molybdenum rod; and "carburizing flux" welding.

Joints made by these three methods and tested without having been heat-treated had about the same tensile strength. Of the heat-treated welds those made by the standard procedure showed less tensile strength than the chromium molybdenum and the carburizing flux welds. The last type showed somewhat higher tensile strengths for all heat-treated specimens of 0.0325 inch thickness and in general for all the thicknesses tested, except at the lowest drawing temperature, 500° F.

Tests made on T-joints in both carbon and chromium molybdenum steel tubing of 1.5 inches outside diameter by 0.058-inch wall, show the inserted-gusset type of reinforcement to be the best considering strength, stiffness, weight, and ease of welding.

Tests are being continued on tubular joints heat-treated after welding and on joints made in thin-walled tubing of 1.5 inches outside diameter by 0.020-inch wall.

TEMPORARY SUBCOMMITTEE ON RESEARCH PROGRAM ON MONOCOQUE DESIGN

Stressed-Skin, or Monocoque, Structures.—During the past year, research on stressed-skin, or monocoque, structures for aircraft has consisted largely of fundamental studies concerning the strength and behavior of skin and stiffeners. Where possible, such phases of the general subject have been summarized in useful form for the designer.

In order that the industry and others interested in research on stressed-skin structures may be kept informed regarding the work of the subcommittee, a brief summary of the minutes of each meeting is prepared for circulation. These minutes record the suggestions that are made from time to time regarding problems suitable for research (in other than Government laboratories).

The subcommittee is now preparing a chart showing the present status of research on stressed-skin structures. Accompanying the chart will be a bibliography and brief discussion of the most authoritative literature on the various phases of the subject.

Research on thin-walled cylinders.—Last year the Committee published a preliminary report on the strength of thin-walled cylinders in torsion. This year a more complete report on the same subject is being published under the authorship of Dr. L. H. Donnell of the California Institute of Technology (Technical Report No. 479). In the recent report, all the available test data on thin-walled cylinders in torsion are included and the results correlated with theory.

A report on the strength of thin-walled cylinders in compression is now in the process of publication (Technical Report No. 473). In this report all the available test data are included, together with the results of tests made by the Committee and by the California Institute of Technology. The results of the tests are presented in nondimensional form and discussed in connection with existing theory.

A report on the strength of thin-walled cylinders in pure bending is also in process of publication (Technical Note No. 479). In this report no consideration is given to theory but the results are presented in nondimensional form for comparison with the results of similar tests in compression published in Technical Report No. 473. The important conclusion regarding the strength of thin-walled cylinders in bending is that the stress on the extreme fiber at failure as calculated by the ordinary theory of bending is from 30 to 80 percent greater than the compressive strength at failure for thin-walled cylinders of the same dimensions.

A report on the strength of thin-walled cylinders of circular section subjected to combined transverse shear and bending is in progress. This report also covers work which is largely experimental, but the results are presented in nondimensional form and compared with the results of torsion and bending tests previously reported. The tests show that, for large values of the ratio of moment to radius-shear (M/rV), the cylinder fails in bending and the stress on the extreme fiber at failure, as calculated by the ordinary theory of bending, is equal to the stress on the extreme fiber at failure for a cylinder of the same dimensions in pure bending. For small values of M/rV, the cylinder fails in shear and the maximum shearing stress at failure as calculated by the oridinary beam theory is approximately equal to the shearing stress at failure for a cylinder of the same dimensions in torsion (pure shear). For intermediate values of M/rV, there is a transition from failure by bending to failure by shear that is accompanied by a reduction in strength. In calculating the strength of the cylinder, this reduction in strength may be allowed for by a proper consideration of the dispersion of the results of the tests on thin-walled cylinders in pure bending.

Strength tests on thin-walled truncated cones and thin-walled cylinders of elliptic section have been completed. The results of these tests will be published later.

Research on strength of stiffeners.—After the airplane division of the Ford Motor Co. suspended operations last year a large portion of the engineering data accumulated from its researches on various types of structural elements was made available to the committee. As a portion of these data revealed that valuable information regarding local failure in stiffeners could be obtained, it is now being condensed for issuance in one or more reports. The reports as finally published will include design charts with the critical stresses plotted against the proper dimensions of the stiffener sections.

Research on strength of stiffened skins.—In collaboration with Professor Niles of Stanford University, the Committee is preparing for publication a general report summarizing all the tests made to date on the compressive strength of corrugated sheet. The data for use in this report have been assembled from various sources, including the Army, the Navy, aircraft manufacturers, and the Massachusetts Institute of Technology. In this report the strength of corrugated sheet for the various types of failure will be presented in chart form correlated with the column curve for the material. Consideration will also be given to the effect of pitch-line curvature on the strength of corrugated sheet and the effect of nonuniform spacing of transverse rings on the column strength of the corrugations.

During the past year the Committee published a report on the compressive strength of flat and slightly curved sheet and stiffener combinations (Technical Note No. 455). In this report the accuracy of three methods based upon various assumptions for calculating the compressive strength of flat sheet and stiffener combinations was compared. The method based upon mutual action of the stiffener and on effective width of sheet as a column gave the best agreement with the results of tests. The investigation of the effect of small curvature presented in the report resulted in the conclusion that the compressive strength of curved panels is, for all practical purposes, equal to the strength of flat panels except for thick sheet where nonuniform curvature throughout the length of the panel may cause the strength of a curved panel to be as much as 10 to 15 percent less than the strength of a corresponding flat panel.

Design of rings.—During the past year the Committee published two reports on the stress analysis of rings (Technical Notes Nos. 444 and 462). By use of the formulas and charts presented in these reports the designer is relieved of the necessity of making a least-work analysis when calculating the stresses in circular and elliptic rings for the majority of loading conditions that are likely to be imposed on the main frames of a monocoque fuselage. The study is being extended to an analysis of the forces that act upon the intermediate rings between the main rings of monocoque fuselages.

Design of beams having thin webs in diagonal tension.—During the past year a study was made and a report prepared (Technical Note No. 469) summarizing the essential formulas for the design of diagonal tension field beams; that is, beams with very thin webs, the theory of which was developed by Professor Wagner of Germany. The purpose of this report was to present in condensed form a brief summary of the fundamental principles and useful formulas for the specific use of the designer.

SUBCOMMITTEE ON METHODS AND DEVICES FOR TESTING AIRCRAFT MATERIALS AND STRUCTURES

The Committee has continued the work on the survey of methods and devices for testing aircraft materials and structures, with a view to publication of the material in a series of reports dealing with various phases of the testing of aircraft materials and structures. At the request of the Subcommittee on Aircraft Structures, priority is being given to a special report on extensometers which is being prepared for publication.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS

Development of fire-resistant dope for aircraft.—The available cellulose esters and synthetic resins were investigated to ascertain their relative values in rendering dopes for airplane wing fabric nonflammable. None of the resins studied gave satisfactory tautness. Cellulose acetate dope was found to be the most satisfactory fire-resistant material of all the products examined. Additional protection is obtained by impregnating the fabric with an aqueous solution of a boric acid-borax mixture before applying the cellulose acetate dope. Fabric fireproofed and doped in this manner is not ignited by lighted matches, cigarettes, redhot nails, nor burning gasoline. The amount of fireproofing salt mixture required on the cloth is approximately 5 percent of the total weight of the doped fabric.

REPORT OF COMMITTEE ON PROBLEMS OF AIR NAVIGATION

In response to the need for the coordination of scientific research being conducted by a number of different agencies, both within and without the Government, on the problems of air navigation, the National Advisory Committee for Aeronautics has established a committee on problems of air navigation, with members representing the principal agencies concerned with the development of aids to air navigation.

In order to cover effectively the large and varied field of research and development on problems of air navigation, the following subcommittees have been organized under the committee on problems of air navigation: subcommittee on instruments and subcommittee on meteorological problems.

PART II

ORGANIZATION AND GENERAL ACTIVITIES

ORGANIZATION

The National Advisory Committee for Aeronautics is composed of 15 members appointed by the President and serving as such without compensation. The law provides that the members shall include 2 representatives each from the War and Navy Departments and 1 each from the Smithsonian Institution, the Weather Bureau, and the Bureau of Standards, together with not more than 8 additional persons "who shall be acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." One of these eight is a representative of the Aeronautics Branch of the Department of Commerce. Under the rules and regulations governing the work of the Committee as approved by the President the chairman and vice chairman of the committee are elected annually.

On July 12, 1933, President Roosevelt appointed Dr. Lyman J. Briggs a member of the committee to succeed Dr. George K. Burgess, whose death on July 2, 1932, had been noted in the preceding annual report. Dr. Briggs had succeeded Dr. Burgess as director of the Bureau of Standards, and his membership on the Committee is as a representative of that Bureau.

The first vacancy occurring during the past year was caused by the tragic death of Rear Admiral William A. Moffett, United States Navy, Chief of the Bureau of Aeronautics, Navy Department, who was killed in the destruction by storm of the airship *Akron* on April 4, 1933. For 12 years he had served on this Committee faithfully and with great distinction. His outstanding service as a member was his uniform sincerity in fostering truly cooperative efforts in order to prevent duplication in the field of fundamental research in aeronautics. His colleagues adopted resolutions mourning his loss and testifying to the enduring value of his great work for the development of aviation for national defense.

Rear Admiral Ernest J. King, United States Navy, succeeded Admiral Moffett as Chief of the Bureau of Aeronautics, and on July 19, 1933, he was appointed by President Roosevelt to succeed Admiral Moffett as a member of this Committee.

A second vacancy during the year was caused by the resignation on November 9, 1933, of Dr. William F. Durand, who was one of the original members appointed by President Wilson in 1915. Dr. Durand had served as chairman of the Committee in 1916 and 1917. He resigned because his residence on the Pacific coast made it difficult for him to attend meetings frequently, and was succeeded as a member of the Committee by Mr. Eugene L. Vidal, Director of Aeronautics, Department of Commerce.

The executive offices of the Committee, including its offices of aeronautical intelligence and aeronautical inventions are located in the Navy Building, Washington, D.C., in close proximity to the air organizations of the Army and Navy.

The office of aeronautical intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. It is the designated depository for scientific and technical data on aeronautics secured from all parts of the world. The material is classified, cataloged, and disseminated.

To assist in the collection of scientific and technical data, the Committee maintains a technical assistant in Europe with headquarters at the American Embassy in Paris.

CONSIDERATION OF AERONAUTICAL INVENTIONS

In accordance with act of Congress approved July 2, 1926, as amended by act approved March 3, 1927, the Committee passes upon the merits of aeronautical inventions and designs submitted to any branch of the Government and submits reports thereon to the Aeronautical Patents and Design Board, consisting of Assistant Secretaries of the Departments of War, Navy, and Commerce. That board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

The work of considering aeronautical inventions and designs submitted is under the supervision of the committee on aeronautical inventions and designs.

SUBCOMMITTEES

The executive committee has organized a number of standing committees, with subcommittees, for the purpose of supervising its work in their respective fields. The four technical committees on aerodynamics, power plants for aircraft, materials for aircraft, and problems of air navigation, and their subcommittees supervise and direct the areonautical research conducted by the Advisory Committee and coordinate the investigations conducted by other agencies. Their work has been described in part I

The organization of the committees and subcommittees under the executive committee is as follows:

COMMITTEE ON AERODYNAMICS

Dr. David W. Taylor, chairman.
Dr. L. J. Briggs, Bureau of Standards.
Theophile dePort, Matériel Division, Army Air Corps, Wright Field.
Lt. Comdr. W. S. Diehl (C.C.), United States Navy.
Dr. H. L. Dryden, Bureau of Standards.
Richard C. Gazley, Aeronautics Branch, Department of Commerce.
Maj. C. W. Howard, United States Army, Matériel Division, Air Corps, Wright Field.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Dr. Charles F. Marvin, Weather Bureau.
Lt. Comdr. Donald Royce (C.C.), United States Navy.
Hon. Edward P. Warner, editor of Aviation.
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LANGLEY MEMORIAL AERONAUTICAL LABORATORY

The Committee's laboratory is located on the Army flying field, known as "Langley Field, Va.", on ground set aside by the War Department for the Committee's use. The laboratory is subject to the military police, fire, and sanitary regulations governing the post, but is otherwise under the exclusive and direct control of the Committee. The Committee's research work is conducted without interference with military operations at the field, and there is a splendid spirit of cooperation which has materially aided the Committee in its work.

As many of the Committee's fundamental researches are based upon requests received from the Army and Navy for the investigations of particular problems, there has been full cooperation on the part of the Army and Navy in placing at the Committee's disposal airplanes, engines, and accessories needed for research purposes.

The Committee's laboratories comprise 11 buildings and a paid research staff of 260 employees.

ANALYSIS OF AIRCRAFT ACCIDENTS

A standard procedure for the analysis of aircraft accidents proposed by the committee on aircraft accidents, approved by the executive committee, and published as Technical Report No. 357, is followed by the War, Navy, and Commerce Departments. Uniformity in interpretation of the Committee's plan is secured through meetings of the committee on aircraft accidents, which includes in its membership representatives of the War, Navy, and Commerce air organizations. The result is to render accident statistics comparable and thus through the accurate determination of the causes of accidents to be enabled to take appropriate measures for the reduction of accidents due to such causes.

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The Committee has four series of publications, namely, technical reports, technical notes, technical memorandums, and aircraft circulars.

The technical reports present the results of fundamental research in aeronautics. The technical notes are mimeographed and present the results of short research investigations and the results of studies of specific detail problems which form parts of long investigations. The technical memorandums are mimeographed and contain translations of important foreign aeronautical articles. The aircraft circulars are mimeographed and contain descriptions of new types of foreign aircraft.

The following are lists of the publications issued:

LIST OF TECHNICAL REPORTS ISSUED DURING THE PAST YEAR

No.

441. A Flight Investigation of the Spinning of the *NY-1* Airplane with Varied Mass Distribution and Other Modifications, and an Analysis Based on Wind-Tunnel Tests. By Nathan F. Scudder, National Advisory Committee for Aeronautics.
442. A Comparison between the Theoretical and Measured Longitudinal Stability Characteristics of an Airplane. By Hartley A. Soulé and John B. Wheatley, National Advisory Committee for Aeronautics.
443. Pressure-Distribution Measurements on the Hull and Fins of a 1/40-Scale Model of the U.S. Airship *Akron*. By Hugh B. Freeman, National Advisory Committee for Aeronautics.
444. Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. VI—Skewed Ailerons on Rectangular Wings. By Fred E. Weick and Thomas A. Harris, National Advisory Committee for Aeronautics.
445. Working Charts for the Determination of the Lift Distribution between Biplane Wings. By Paul Kuhn, National Advisory Committee for Aeronautics.
446. Airfoil Section Characteristics as Affected by Protuberances. By Eastman N. Jacobs, National Advisory Committee for Aeronautics.
447. Static Thrust of Airplane Propellers. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
448. Improved Apparatus for the Measurement of Fluctuations of Air Speed in Turbulent Flow. By W. C. Mock, Jr., and H. L. Dryden, Bureau of Standards.
449. Wing Characteristics as Affected by Protuberances of Short Span. By Eastman N. Jacobs and Albert Sherman, National Advisory Committee for Aeronautics.
450. The Calculation of Take-Off Run. By Walter S. Diehl, Bureau of Aeronautics, Navy Depatment.
451. The Drag of Two Streamline Bodies as Affected by Protuberances and Appendages. By Ira H. Abbott, National Advisory Committee for Aeronautics.

No.

452. General Potential Theory of Arbitrary Wing Sections. By T. Theodorsen and I. E. Garrick, National Advisory Committee for Aeronautics.
453. The Estimation of Maximum Load Capacity of Seaplanes and Flying Boats. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
454. Photomicrographic Studies of Fuel Sprays. By Dana W. Lee and Robert C. Spencer, National Advisory Committee for Aeronautics.
455. Penetration and Duration of Fuel Sprays from a Pump Injection System. By A. M. Rothrock and E. T. Marsh, National Advisory Committee for Aeronautics.
456. The Aerodynamic Forces and Moments Exerted on a Spinning Model of the *NY-1* Airplane as Measured by the Spinning Balance. By M. J. Bamber and C. H. Zimmerman, National Advisory Committee for Aeronautics.
457. Maneuverability Investigation of an *O3U-1* Observation Airplane. By F. L. Thompson and H. W. Kirschbaum, National Advisory Committee for Aeronautics.
458. Relative Loading on Biplane Wings. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
459. The N.A.C.A. Full-Scale Wind Tunnel. By Smith J. DeFrance, National Advisory Committee for Aeronautics.
460. The Characteristics of 78 Related Airfoil Sections from Tests in the Variable-Density Wind Tunnel. By Eastman N. Jacobs, Kenneth E. Ward, and Robert M. Pinkerton, National Advisory Committee for Aeronautics.
461. Interference on an Airfoil of Finite Span in an Open Rectangular Wind Tunnel. By Theodore Theodorsen, National Advisory Committee for Aeronautics.
462. Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. III—Clark Y Wing—Various Radial-Engine Cowlings—Tractor Propeller. By Donald H. Wood, National Advisory Committee for Aeronautics.
463. The N.A.C.A. High-Speed Wind Tunnel and Tests of Six Propeller Sections. By John Stack, National Advisory Committee for Aeronautics.
464. Negative Thrust and Torque Characteristics of an Adjustable-Pitch Metal Propeller. By Edwin P. Hartman, National Advisory Committee for Aeronautics.
465. Determination of the Theoretical Pressure Distribution for Twenty Airfoils. By I. E. Garrick, National Advisory Committee for Aeronautics.
466. Aircraft Power-Plant Instruments. By Harcourt Sontag and W. G. Brombacher, Bureau of Standards.
467. The Experimental Determination of the Moments of Inertia of Airplanes. By Hartley A. Soulé and Marvel P. Miller, National Advisory Committee for Aeronautics.
468. The Interference between Struts in Various Combinations. By David Biermann and William H. Herrnstein, Jr., National Advisory Committee for Aeronautics.
469. Increasing the Air Charge and Scavenging the Clearance Volume of a Compression-Ignition Engine. By J. A. Spanogle, C. W. Hicks, and H. H. Foster, National Advisory Committee for Aeronautics.
470. The N.A.C.A. Tank. A High-Speed Towing Basin for Testing Models of Seaplane Floats. By Starr Truscott, National Advisory Committee for Aeronautics.
471. Performance of a Fuel-Injection Spark-Ignition Engine Using a Hydrogenated Safety Fuel. By Oscar W. Schey and Alfred W. Young, National Advisory Committee for Aeronautics.

No.

472. Wind-Tunnel Tests on Combinations of a Wing with Fixed Auxiliary Airfoils Having Various Chords and Profiles. By Fred E. Weick and Robert Sanders, National Advisory Committee for Aeronautics.
473. Strength Tests of Thin-Walled Duralumin Cylinders in Compression. By Eugene E. Lundquist, National Advisory Committee for Aeronautics.
474. Nomenclature for Aeronautics. By National Advisory Committee for Aeronautics.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.

432. Drag Tests of 4/9-Scale Model Engine Nacelles with Various Cowlings. By Ray Windler, National Advisory Committee for Aeronautics.
433. The Pressure Distribution Over a Standard and a Modified Navy Elliptical Wing Tip on a Biplane in Flight. By Richard V. Rhode, National Advisory Committee for Aeronautics.
434. Influence of Several Factors on Ignition Lag in a Compression-Ignition Engine. By Harold C. Gerrish and Fred Voss, National Advisory Committee for Aeronautics.
435. The Effect of Clearance Distribution on the Performance of a Compression-Ignition Engine with a Precombustion Chamber. By C. S. Moore and J. H. Collins, Jr., National Advisory Committee for Aeronautics.
436. The Effect of Connecting-Passage Diameter on the Performance of a Compression-Ignition Engine with a Precombustion Chamber. By C. S. Moore and J. H. Collins, Jr., National Advisory Committee for Aeronautics.
437. The Pressure Distribution Over a Long Elliptical Wing Tip on a Biplane in Flight. By Richard V. Rhode, National Advisory Committee for Aeronautics.
438. The Gaseous Explosive Reaction at Constant Pressure—Further Data on the Effect of Inert Gases. By F. W. Stevens, Bureau of Standards.
439. Meteorological Conditions During the Formation of Ice on Aircraft. By L. T. Samuels, Weather Bureau.
440. Flight Tests to Determine the Effect of a Fixed Auxiliary Airfoil on the Lift and Drag of a Parasol Monoplane. By Hartley A. Soule, National Advisory Committee for Aeronautics.
441. Rolling, Yawing, and Hinge Moments Produced by Rectangular Ailerons (Correlating Technical Reports Nos. 298, 343, and 370). By R. H. Heald, Bureau of Standards.
442. Jet Propulsion with Special Reference to Thrust Augmentors. By G. B. Schubauer, Bureau of Standards.
443. Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part VII—Handley Page Tip and Full-Span Slots with Ailerons and Spoilers. By Fred E. Weick and Carl J. Wenzinger, National Advisory Committee for Aeronautics.
444. Working Charts for the Stress Analysis of Elliptic Rings. By Walter F. Burke, University of Michigan.
445. Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part VIII—Straight and Skewed Ailerons on Wings with Rounded Tips. By Fred E. Weick and Joseph A. Shortal, National Advisory Committee for Aeronautics.
446. Estimation of the Variation of Thrust Horsepower with Air Speed. By Shatswell Ober, Massachusetts Institute of Technology.

No.

447. The Effect on Lift, Drag, and Spinning Characteristics of Sharp Leading Edges on Airplane Wings. By Fred E. Weick and Nathan F. Scudder, National Advisory Committee for Aeronautics.
448. Effect of Aileron Displacement on Wing Characteristics. By R. H. Heald, Bureau of Standards.
449. Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part IX—Tapered Wings with Ordinary Ailerons. By Fred E. Weick and Carl J. Wenzinger, National Advisory Committee for Aeronautics.
450. Mercerization of Cotton for Strength with Special Reference to Aircraft Cloth. By J. B. Wilkie, Bureau of Standards.
451. Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part X—Various Control Devices on a Wing with a Fixed Auxiliary Airfoil. By Fred E. Weick and Richard W. Noyes, National Advisory Committee for Aeronautics.
452. The Importance of Auto-Ignition Lag in Knocking. By E. S. Taylor, Massachusetts Institute of Technology.
453. Experiments with a Counter-Propeller. By E. P. Lesley, Stanford University.
454. The N.A.C.A. Combustion Chamber Gas-Sampling Valve and Some Preliminary Test Results. By J. A. Spanogle and E. C. Buckley, National Advisory Committee for Aeronautics.
455. Comparison of Three Methods for Calculating the Compressive Strength of Flat and Slightly Curved Sheet and Stiffener Combinations. By Eugene E. Lundquist, National Advisory Committee for Aeronautics.
456. The Aerodynamic Effect of a Retractable Landing Gear. By Smith J. DeFrance, National Advisory Committee for Aeronautics.
457. The Aerodynamic Characteristics of Airfoils as Affected by Surface Roughness. By Ray W. Hooker, National Advisory Committee for Aeronautics.
458. Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part XI—Various Floating Tip Ailerons on Both Rectangular and Tapered Wings. By Fred E. Weick and Thomas A. Harris, National Advisory Committee for Aeronautics.
459. Wind-Tunnel Tests on Model Wing with Fowler Flap and Specially Developed Leading-Edge Slot. By Fred E. Weick and Robert C. Platt, National Advisory Committee for Aeronautics.
460. Full-Scale Wind-Tunnel Research on Tail Buffeting and Wing-Fuselage Interference of a Low-Wing Monoplane. By Manley J. Hood and James A. White, National Advisory Committee for Aeronautics.
461. The Effect of Rivet Heads on the Characteristics of a 6- by 36-Foot Clark Y Metal Airfoil. By Clinton H. Dearborn, National Advisory Committee for Aeronautics.
462. Formulas for the Stress Analysis of Circular Rings in a Monocoque Fuselage. By Roy A. Miller, Consolidated Aircraft Corporation, and Karl D. Wood, Cornell University.
463. Aerodynamic Tests of a Low Aspect Ratio Tapered Wing with Various Flaps, for Use on Tailless Airplanes. By Fred E. Weick and Robert Sanders, National Advisory Committee for Aeronautics.
464. A Complete Tank Test of a Model of a Flying-Boat Hull—N.A.C.A. Model No. 11. By James M. Shoemaker and John B. Parkinson, National Advisory Committee for Aeronautics.

No.

465. Some Characteristics of Sprays Obtained from Pintle-Type Injection Nozzles. By E. T. Marsh and C. D. Waldron, National Advisory Committee for Aeronautics.
466. Engine Performance with a Hydrogenated Safety Fuel. By Oscar W. Schey and Alfred W. Young, National Advisory Committee for Aeronautics.
467. Simplified Aerodynamic Analysis of the Cyclogiro Rotating-Wing System. By John B. Wheatley, National Advisory Committee for Aeronautics.
468. A Study of Factors Affecting the Steady Spin of an Airplane. By Nathan F. Scudder, National Advisory Committee for Aeronautics.
469. A Summary of Design Formulas for Beams Having Thin Webs in Diagonal Tension. By Paul Kuhn, National Advisory Committee for Aeronautics.
470. A Complete Tank Test of a Model of a Flying-Boat Hull—N.A.C.A. Model No. 11-A. By John B. Parkinson, National Advisory Committee for Aeronautics.
471. A Complete Tank Test of a Model of a Flying-Boat Hull—N.A.C.A. Model No. 16. By James M. Shoemaker, National Advisory Committee for Aeronautics.
472. The Effect of Partial-Span Split Flaps on the Aerodynamic Characteristics of a Clark Y Wing. By Carl J. Wenzinger, National Advisory Committee for Aeronautics.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

No.

687. Methods for Facilitating the Blind Landing of Airplanes. By M. Heinrich Gloeckner. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, June 24, 1932.
688. Speed and Pressure Recording in Three-Dimensional Flow. By Dr. F. Krisam. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, July 14, 1932.
689. The Problem of Tire Sizes for Airplane Wheels. By Franz Michael. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, July 14, 1932.
690. Transmission of Heat from a Flat Plate to a Fluid Flowing at a High Velocity. By Luigi Crocco. From L'Aerotecnica, February 1932.
691. Some Ideas on Racing Seaplanes. By Giovanni Pegna. From Rivista Aeronautica, June 1932.
692. Methods of Recording Rapid Wind Changes. By A. Magnan. From Jahrbuch No. 4 (1929) des Forschungs-Institutes der Rhön-Rossitten-Gesellschaft.
693. The Testing of Airplane Fabrics. By Karl Schraivogel. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, August 27 and September 14, 1932.
694. Combustion of Gaseous Mixtures. By R. Duchene. From Publications Scientifiques et Techniques du Ministere de l'Air, No. 11, Service des Recherches de l'Aéronautique.
695. Automatic Stability of Airplanes. By Fr. Haus. From L'Aéronautique, May, June, July, and August 1932.
696. The Problem of the Propeller in Yaw with Special Reference to Airplane Stability. By Franz Misztal. From Abhandlungen aus dem Aerodynamischen Institut an der Technischen Hochschule Aachen, No. 11, 1932.
697. The D.V.L. Gliding-Angle Control (W. Hübner Design). By Walter Hübner and Wilhelm Pleines. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, August 12, 1932.
698. Dynamic Breaking Tests of Airplane Parts. By Heinrich Hertel. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, August 14 and August 28, 1931.

No.

699. The Process of Separation in the Turbulent Friction Layer. By E. Gruschwitz. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, June 14, 1932.
700. Increasing the Volumetric Efficiency of Diesel Engines by Intake Pipes. By Hans List. From Mitteilungen aus den technischen Instituten der Staatlichen Tung-Chi Universitat, Report No. 4, April 1932.
701. The Effect of a Gap between Elevator and Stabilizer on the Static Stability and Maneuverability about the Lateral Axis in Flight. By Walter Hübner. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, June 14, 1932.
702. Determination of Inherent Stresses by Measuring Deformations of Drilled Holes. By Josef Mathar. From Archiv für das Eisenhuttenwesen (Communication from the Aachen Aerodynamic Institute), 1932–33.
703. Take-Off and Propeller Thrust. By Martin Schrenk. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, November 14, 1932.
704. Scale Effect of Model in Seaplane-Float Investigations. By W. Sottorf. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, December 28, 1932.
705. The Critical Shear Load of Rectangular Plates. By Edgar Seydel. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, February 14, 1933.
706. Knowledge Gained from Practical Experience in the Designing of Aircraft Engines. By Oskar Kurtz. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, December 14 and December 28, 1932.
707. Experiments with Needle Bearings. By Pericle Ferretti. From Rivista Aeronautica, October 1932.
708. Flight-Test Data on the Static Fore-and-Aft Stability of Various German Airplanes. By Walter Hübner. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, January 28, 1933.
709. Future Problems of Soaring Flight (Report of 1932 Rhön Soaring Contest). By Walter Georgii; and Systematic Observations of Local Cumuli. By Roland Eisenlohr. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, March 14, 1933.
710. Tests for the Elimination of Tail Flutter. By Curt Biechteler. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, January 14, 1933.
711. Pressure Rise, Gas Vibrations, and Combustion Noises During the Explosion of Fuels. By Professor Wawrziniok. From Automobiltechnische Zeitschrift, February 10 and March 10, 1933.
712. The Schneider Trophy Contest. By Alfred Richard Weyl. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, August 12 and August 27, 1932.
713. Behavior of Vortex Systems. By A. Betz. From Zeitschrift für angewandte Mathematik und Mechanik, June 1932.
714. A Simple Method for Increasing the Lift of Airplane Wings by Means of Flaps. By Eugen Gruschwitz and Oskar Schrenk. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, October 28, 1932.
715. Pressure and Frictional Resistance of a Cylinder at Reynolds Numbers 5,000 to 40,000. By L. Schiller and W. Linke. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, April 13, 1933.
716. Development of the Rules Governing the Strength of Airplanes. By H. G. Küssner and Karl Thalau. Part I—German Loading Conditions Up to 1926. From Luftfahrtforschung, June 21, 1932.

No.

717. Development of the Rules Governing the Strength of Airplanes. By H. G. Küssner and Karl Thalau. Part II—Loading Conditions in Germany (Continued), England, and the United States. From Luftfahrtforschung, June 21, 1932.
718. Development of the Rules Governing the Strength of Airplanes. By H. G. Küssner and Karl Thalau. Part III—Loading Conditions in France, Italy, Holland, and Russia—Aims at Standardization. From Luftfahrtforschung, June 21, 1932.
719. Dimensions of Twin Seaplane Floats. By L. Meyer. From Association Technique Maritime et Aeronautique, May 1933.
720. Recent Results of Turbulence Research. By L. Prandtl. From Zeitschrift des Vereines Deutscher Ingenieure, February 4, 1933.
721. Results of Extended Tests of the Focke-Wulf F 19a "Ente", a Tail-First Airplane. By Walter Hübner. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, April 28 and May 13, 1933.
722. Guide Vanes for Deflecting Fluid Currents with Small Loss of Energy. By G. Kröber. From Ingenieur-Archiv, 1932.
723. An Airfoil Spanning an Open Jet. By J. Stüper. From Ingenieur-Archiv, 1932.

LIST OF AIRCRAFT CIRCULARS ISSUED DURING THE PAST YEAR

No.

172. The Messerschmidt M. 29 Touring Airplane (German). A Two-Seat Cantilever Monoplane. From information furnished by the manufacturers, and from Zeitschrift für Flugtechnik und Motorluflschiffahrt, October 14, 1932.
173. Nieuport-Delage 590 Military Airplane (French). A Two-Place High-Wing Cantilever Monoplane. From Revue de la Société Générale Aéronautique, October 1932.
174. The D.H. "Dragon Moth" Commercial Airplane (British). A Twin-Engine Six-Passenger Biplane. From The Aeroplane, December 21, 1932; and Flight, December 22, 1932.
175. Heinkel He 64 c Sport Airplane (German). A Two-Seat Low-Wing Cantilever Monoplane. From data furnished by the manufacturers.
176. The Caudron P.V. 200 Touring Airplane (French). An All-Metal Amphibian Monoplane. From L'Aéronautique, December 1932, January 1933; and from information furnished by the manufacturers.
177. The Boulton and Paul P. 64 Mail-Carrier. A Two-Engine All-Metal Biplane. From The Aeroplane, April 5, 1933.
178. The Airspeed "Courier" Commercial Airplane (British). A Low-Wing Cantilever Monoplane. From The Aeroplane, March 22, 1933.
179. The Westland "Wallace" General-Purpose Airplane (British). An All-Metal Biplane. From Flight, May 4, 1933.
180. The Dewoitine D. 500 Pursuit Airplane (French). An All-Metal Cantilever Low-Wing Monoplane. From data furnished by the manufacturers.
181. The Shackleton-Murray SM-1 Light Airplane. A Two-Place High-Wing Monoplane. From The Aeroplane, May 17, 1933.
182. The Hanriot-Biche 110 C1 Airplane (French). An All-Metal Low-Wing Pursuit Monoplane. By Rene Rabion. From Les Ailes, March 30, 1933; and L'Aéronautique, May 1933.

No.

183. Heinkel He 70 Commercial Airplane (German). A Seven-Seat Cantilever Low-Wing Monoplane. From data furnished by the manufacturers; and Luftwacht, March 1933.

FINANCIAL REPORT

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1933, as carried in the Independent Offices Appropriation Act approved June 30, 1932, was $900,000. In accordance with provisions of the Economy Acts affecting personal services, furlough and compensation deductions amounting to $72,586 were made during the fiscal year. The amount expended and obligated was $827,186, itemized as follows:

Personal services	$600, 043. 86
Supplies and materials	38, 309. 12
Communication service	1, 877. 83
Travel expenses	10, 256. 30
Transportation of things	1, 545. 12
Furnishing of electricity	29, 565. 29
Rent of office (Paris)	960. 00
Repairs and alterations	17, 872. 08
Special investigations and reports	45, 200. 00
Equipment	81, 556. 65
Expenditures	827, 186. 25
Unobligated balance	227. 70
Furlough and compensation deductions	72, 586. 05
Total, general appropriation	900, 000. 00

The appropriation for printing and binding for 1933 was $15,000, of which $14,983 was expended.

The sum of $6,780.82 was collected by this Committee during the fiscal year 1933, for scientific services furnished private parties, and this amount was deposited in the Treasury to the credit of Miscellaneous Receipts.

The appropriations for the current fiscal year 1934 are $676,000 for general expenses and $19,000 for printing and binding.

On August 23, 1933, a severe storm inundated Langley Field and 9 of the 11 Committee laboratories were flooded with salt water, reaching a maximum depth of 5 feet in the full-scale wind tunnel. Damage also resulted to the walls of several structures from the battering effect of waves and debris from Chesapeake Bay, backed by winds of hurricane intensity.

The Committee had previously obtained an allotment of $200,000 from the Public Works Administration for needed items of construction and repair. Immediately after the storm the Public Works Administration authorized the expenditure of as much of the $200,000 as might be necessary to repair the storm damage. This prompt action made it possible to minimize the direct and consequential damages. The cost of such emergency repairs was $47,944, and an additional allotment of this amount was subsequently made by the Public Works Administration for this purpose.

CONCLUSION

The Committee is grateful to the President and to the Congress for the liberal support that has been given to its work. It is proud of the contributions it has made to the progress of American aeronautics. It is glad to have the opportunity thus to make further contributions to the progress of civilization, for the history of the human race shows that man's progress has kept pace with improvements in transportation. Each improvement in the performance, efficiency, and safety of aircraft increases the relative importance of aviation to the national defense, and hastens the advent of the era when air travel will grow with increased safety and flourish on a sound economic basis.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS,
JOSEPH S. AMES, *Chairman*.